SUBJECT-IN-THE-LOOP VOICE FEEDBACK CONTROL

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Abstract: A subject-in-the-loop feedback control system is composed of a bioengineering system including a subject, whose voice is received by a microphone, a computer that achieves the required signal processing of the sound signal by temporal and/or spectral computations and a speaker or earphones for auditory feedback to the subject of voice training. Frequency domain modifications of the signal are intended for voice training of subjects already familiar with traditional voice training. The objective of this paper is to present alternative methods for the implementation of subject-in-the-loop feedback control systems developed for voice training. The proposed feedback control scheme is an extension of the traditional control systems; feedback sensing and the control law are achieved by the human subject as a self-organizing controller. The experimental set-ups, developed for this purpose, contain programmable digital devices for real time modifications of the frequency content of the voice signal. The paper presents also a preliminary solution that satisfies the requirements for real-time operations, in particular that the subject does not perceive the delay between the sound generation and the auditory reception of the modified sound. The system performs also spectral calculations for the analyses of the vocal sound signals. Preliminary experimental results illustrate the operation and the features of the proposed subject-in-the-loop real-time system for voice training.

1 INTRODUCTION

The purpose of this research work is to develop a bioengineering experimental set-up with real-time capability for voice signal processing in a closed loop configuration. Acoustic loops refer to systems for signal amplitude increase or decrease of certain sound frequencies using digital manipulation of sound samples. The goal of this research is the design and the construction of computer based modules for actors' voice training, as well as, for singers and public speakers who were already subjected to traditional voice training. Such an Audio-Formant Mobility Trainer is an adjunct to voice-training. The reason for previous training requirement results from the fact that the subject will have to produce different voice qualities for which it is necessary to have acquired a certain mobility of the bodily parts that produce speech. The device is

intended to facilitate the production of new voice qualities by increasing the mobility of one's voice formants. The Audio-Formant Mobility Trainer is a module that can perform acoustical the subject's voice and band-pass filtering for each of the formants for the purpose of auditory-feedback. Any formant can hence be chosen to be manipulated in order to increase the ability of the subject to perceive it in his own voice. There are three types of formant manipulations:

1. Intensity: varying the relative intensity of the formant bandwidth ranging from filtering it out to increasing it above the spectral envelope.
2. Bandwidth: Increasing and decreasing its width.
3. Pitch: Increasing and decreasing its pitch.

Typically, the learner uses a microphone and headphones while singing or speaking. His voice is

analyzed and processed through the computer. This training could be very useful for actors and singers who are called to produce different voice types. It may be also helpful for learners of new vowels in analysis called LTAS (Long Time Average Spectra), thereby determining the formants that characterize foreign language. Preliminary research work (Necsulescu and Weiss et al., 2006, 2005, 2008) led to the confirmation that complex acoustic phenomena can be properly simulated for the needs of designing acoustic hardware in the form of a closed loop experimental set-up for acoustics analysis. The present stage is the construction of an experimental set-up with real-time capabilities and of-line spectral analysis and its testing with human subjects. The specificity of this closed loop control system is the presence of the human subject in the loop in lieu of the traditional physical only system. The presence of the subject in the control loop results in interesting new issues for the feedback control design.

2 AUDITORY FEEDBACK AND VOICE PRODUCTION

Previous research showed that changing voice quality by altering the auditory perception of one's voice is, to a limited degree, possible. If a person's sound production possibilities are enlarged (through voice training), then altered auditory feedback might facilitate the generation of different voice qualities (Necsulescu, Weiss, and Pruner, 2008). The set-up consists in a subject hearing his voice through headphones while speaking into a microphone. However, the process allows a series of digital manipulations (temporal and spectral) designed to affect perception while examining the effects on vocal output. Whereas, the intensity feedback manipulations have been studied extensively (Purcell, and Munhall, Vol. 119 2006), (Purcell and Munhall 120, 2006), spectral changes effects on voice quality in auditory feedback and their relationship to voice production are still relatively unknown. Original proponents of the use of servo mechanical theory have claimed a direct effect on the vocal output when modified voice is fed back to the speaker. Essentially, according to this theory, if certain bandwidths of the voice spectra are modified in such a manner as to increase or decrease the energy in those regions, the person emitting those sounds will unconsciously react if the modified voice signal is fed back to his ears. The possibility of affecting voice output by auditory feedback remains a topic of intense interest for those involved in voice, speech and accent training (Weiss, 2006), (Necsulescu, Weiss and Pruner, 2008).

Therefore, it would be important to verify the possibility of bandwidth and formant modification. It is expected that subjects, who have undergone voice training, could emulate different spectral characteristics fed-back through auditory filtering, by increasing or attenuating energy in particular spectral zones of their voice.

This work has the long-term goal to carry out audio-vocal filtering experiments with subjects with or without vocal training in order to determine whether voice training could allow for vocal adjustments in conditions related to filtered auditory feedback. This paper describes the construction of computer based module for auditory feedback with no perceived temporal delay.

There are many teaching techniques in voice training, some auditory, some movement based and some mixed. Independently of the technique, certain pedagogical approaches are often used. One is bodily awareness through minimal movements (Purcell and Munhall, 2006) an approach having as a goal an effortless speech-motor learning system. A variable is introduced and the subject perceives it, plays with it, explores it, adjusts to it and integrates it in his own behaviour. This is the purpose of the Audio-Formant Mobility Trainer, an adjunct to voice-training when the learner has had already preliminary training with any traditional technique. The reason for the need for previous training is that the subject will have to produce different voice qualities for which it is necessary to have acquired a certain control of the mobility of the bodily parts that produce speech. The purpose of the device is expected to facilitate the production of new voice qualities by increasing the mobility of one's voice formants.

3 DESCRIPTION OF EXPERIMENT

Our first experiment tries to ascertain whether it is possible to teach subjects to vary their fourth formant (F_4) at will. Previous research (Purcell, and Munhall, Vol. 119, 2006), (Weiss, 2006) has shown that subjects do it unconsciously when their auditory feedback is manipulated while uttering vowels. It is also known (Purcell and Munhall, 2006), that formant manipulation in pitch and bandwidth
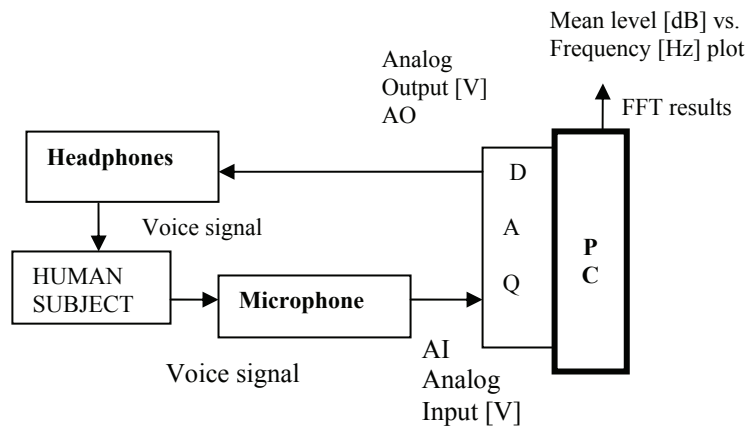
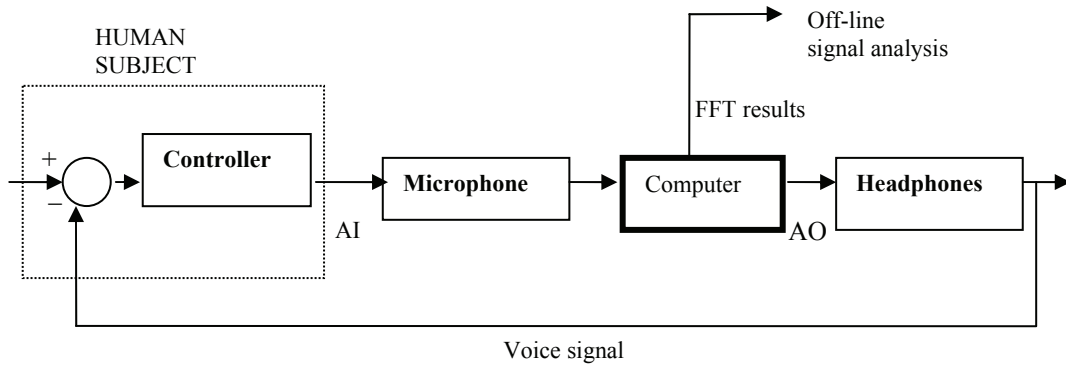Figure 1: Block diagram of a generic auditory feedback system.

Figure 2: Block diagram of the auditory feedback system in feedback control (regulator) configuration.
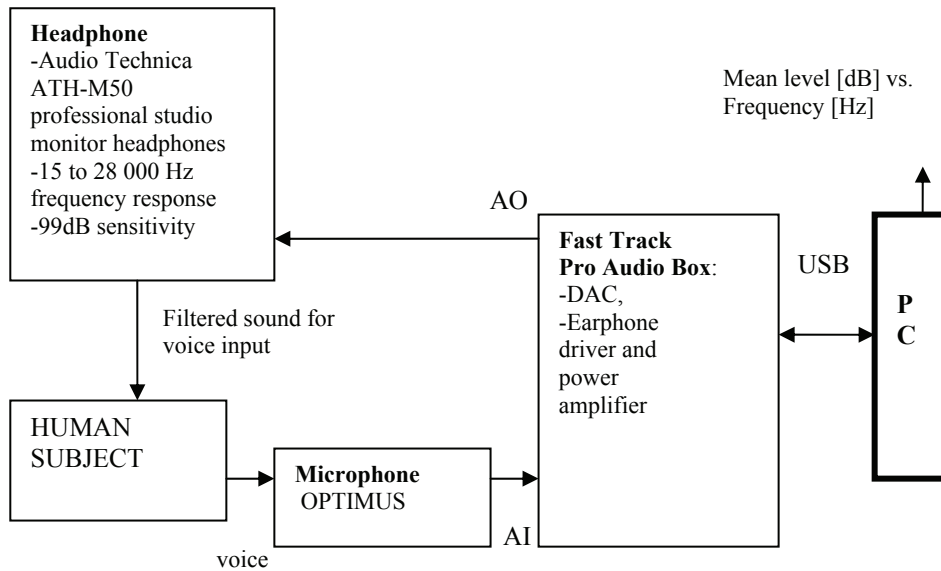

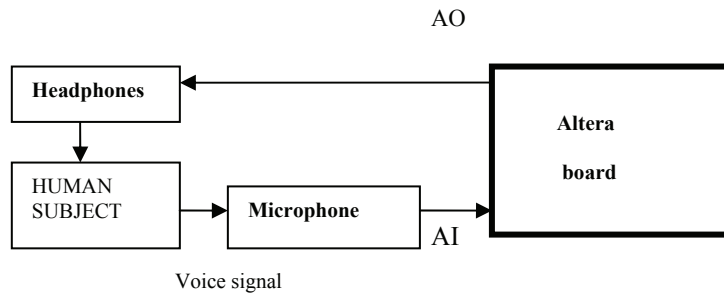Figure 3: Block diagram of the PC based auditory feedback system.

AO

Figure 4: Block diagram of an Altera board based auditory feedback system.
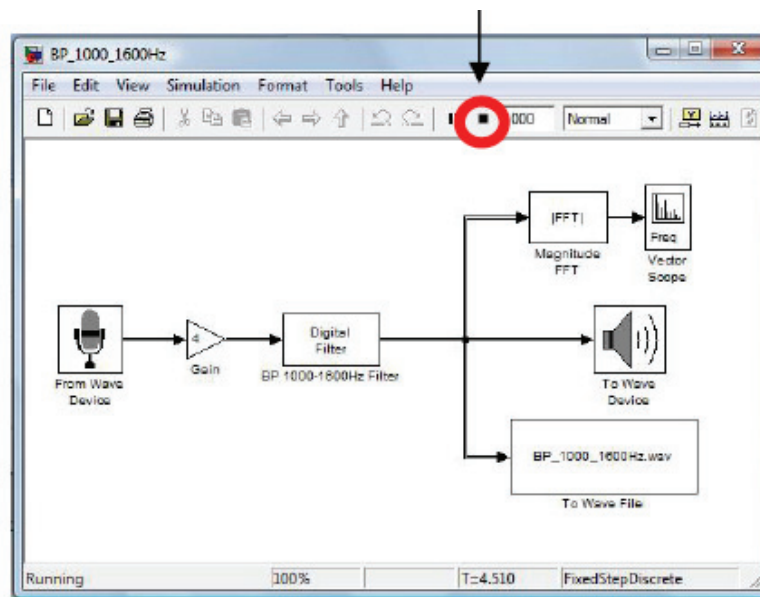

Figure 5: The diagram of the real-time system for signal acquisition from AI, filtering, FFT frequency analysis, display and headphone signal generation to AO.

changes significantly the perceived voice quality. A new and useful approach to producing new voice qualities is important voice training.

4   EXPERIMENTAL SET-UP

The task of the experimental set-up is to test the subjects in the following auditory feedback conditions:

   a. Filtering spectral envelope of maxima in the subject speech.
   b. Filtering spectral envelope of minima   in the subject's speech.
   c. Low Pass filtering (LP)
   d. High Pass filtering Hz (HP)
   e. Band Pass filtering.
   f. No filtering

The main difficulty until recently was to achieve real-time capability in auditory feedback with programmable digital hardware. Some delay in auditory feedback could not be avoided, but it is desired to reduce it such that it will not be perceived.

In the proposed experimental set-up, using recent hardware equipment and advanced software, it was possible to achieve above requirements.

The block diagram of the complete auditory feedback system is shown in Figure 1. Figure 2 shows this system in the traditional control system block diagram form. A human subject carries out in this case the feedback sensing, the comparator and the controller (regulator).

Figure 3 shows the block diagram of the PC based auditory feedback system, while Figure 4 shows another implementation using a single board computer, an Altera board.

Figure 5 shows the Simulink^R diagram of the real-time system for signal acquisition from AI, filtering, FFT frequency analysis, display and headphone signal generation to AO (Necsulescu, Weiss and Pruner, 2008).

This paper presents the results of testing the PC based auditory feedback experimental set-up. The results for an Altera-based system will be presented in a subsequent paper.

5 PRELIMINARY EXPERIMENTAL SET-UP TESTING RESULTS

The experimental setup was tested for verifying its performance. The current subject, used for experiments, has had extensive voice training. He sang for each audio-vocal filtering condition a 60 seconds French song using a neutral vowel.

MATLAB representation of the amplitude versus time and the calculation of the Long Term Average Spectra (LTAS), permits the evaluation of the effects of voice signal processing (Purcell and Munhall, 2006).

Figure 6 shows the frequency domain results of the sound signal in case of no headphones. These results are post-processed in frequency domain for the identification of formants.

A visual inspection of the figure allows us to choose one of the peaks, for example 3300 Hz, for the recording of the voice produced with auditory feedback in real time of the formant manipulations.
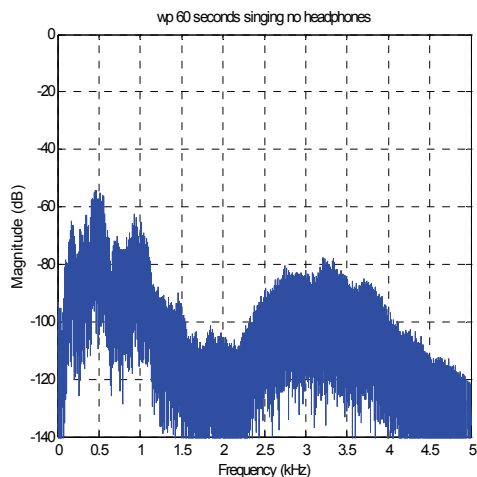
Figure 6: Results for LTAS of the sound signal with no headphones.

Figure 7 shows formant manipulation of the voice with LTAS for 500 Hz bandstop filtering.

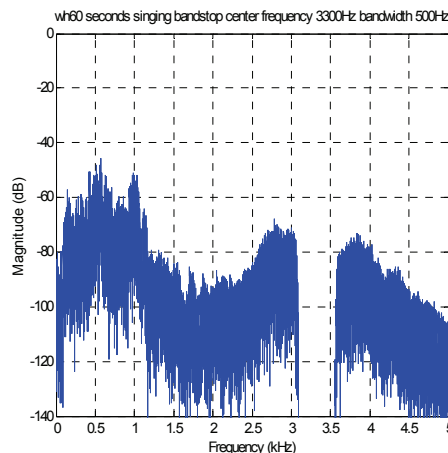This figure shows what the subject heard following signal manipulation.

Figure 7: Formant manipulation of the voice with LTAS for 500 Hz bandstop filtering.
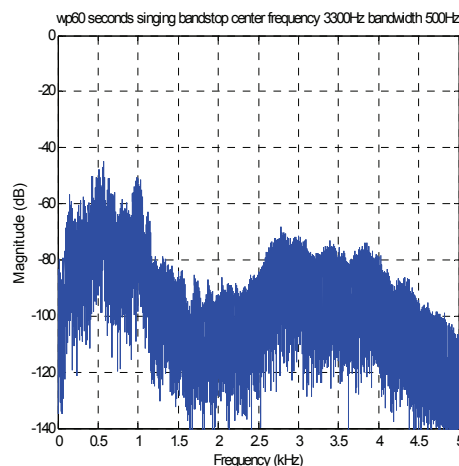
Figure 8: Recording the effects for the 500 Hz bandstop filtering.

Bandstop hearing while singing produces a typical 3 zone spectrum: 1. The highest peaks, from fundamental frequency to 1100 Hz; 2. The second highest peaks, from 2500 to 3500-4000 Hz; 3. A Bowl, from 1100 to 2500 Hz. The 500 Hz bandstop produces a clear peak between 3500-4000 Hz. This indicates that the bigger the gap the bigger the compensation. After hearing the signal shown in Figure 7, the resulting spectral form from Figure 8 appear similar in this case to the one produced while singing without headphones, shown in Figure 6.

Figure 9 shows the results of the intensified

amplitude of a 500 Hz about 3300 Hz. After hearing the signal shown in Figure 9, the subject produces the signal with the spectral content shown in Figure 10.
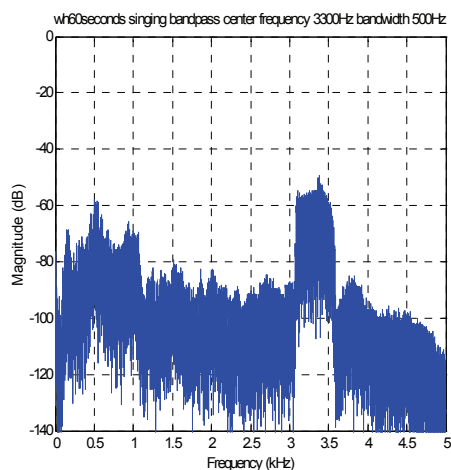

Figure 9: Formant manipulation of the voice with LTAS for 500 Hz frequency band amplification.
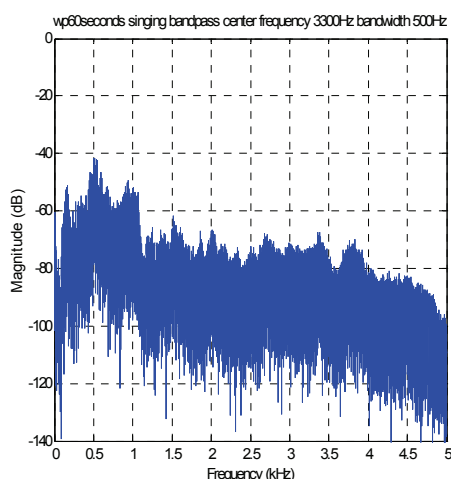

Figure 10: Recording of the effects of the 500 Hz frequency band amplification.

The spectral form from Figure 10 differs significantly from the results from Figure 6, for the case of no headphones. The spectrum is flattened when compared to the three-zone spectrum of no headphones condition. This confirms that the real time signal was reduced to the desired frequency domain and the audio test based on the system shown in Figure 2 confirmed subjectively the validity of this result. This preliminary confirmation of the significant effects on the subject of signal processing, is an encouraging result for the prospect of using in voice training.

The subject produced different voice qualities unconsciously when given different auditory feedback conditions. The approach seems useful for training the voice for different voice qualities.

The results for the Altera board implementation will be presented in a subsequent paper.

6   CONCLUSIONS

This experimental setup is useful in for the voice training experiments for selected subjects using:
- Long term average spectra under each condition.
- Processing and storing data in the computer.
- Comparison of spectra under filtering and no filtering conditions.
- Comparison of experimental [trained] and non-trained groups.

The proposed auditory feedback experimental set-up proved to satisfy the requirements of acquiring signals with a microphone and filtering, displaying and transmitting the modified signals to the earphones in real time. Moreover, auditory signals were FFT processed for the successful identification of each particular subject formants. This experimental set-up was deemed appropriate for purposes of voice training for selected subjects.

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