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# A WEARABLE, VIBROTACTILE /S/-MONITOR FOR HEARING IMPAIRED BASED ON SPECTRAL SIMILARITY MEASURES

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## ABSTRACT

The development of a dual-modality hearing prosthesis is described that utilizes vibrotactile stimulation of the ear for /s/ and /z/ phoneme sounds of speech and amplified acoustic stimulation for other sounds that fall within the usable range of the impaired ear. The work has focussed on the development of a method for detection of the /s/ and /z/ phonemes from the acoustic signal under natural conditions of conversational speech and on an efficient implementation of a piezoelectric vibrotactile transducer that can be incorporated into an ear-level module.

## INTRODUCTION

While most hearing-impaired persons can produce /s/ and /z/ phoneme sounds in isolation, during controlled practice, or when reminded to do so, few of them regularly produce the sounds so that they are audible in their own conversational speech. The /s/ sound and its voiced cognate /z/ are important in spoken English since they occur frequently and carry essential syntactic information such as plural and possessive forms. The difficulty of the hearing-impaired in monitoring their production of these sounds is caused by lack of acoustic feedback information. To further complicate matters little kinesthetic and tactile feedback is present in the production of these sounds. Our goal, therefore, is to develop a practical, wearable feedback device that vibrates the ear canal when an /s/ sound is properly produced by the wearer. To be useful, the device must be capable of operating under natural conditions of background noise and discriminating the /s/ and /z/ sounds from other fricative sounds. The device should also be usable in conjunction with a conventional acoustic hearing aid so that further benefit can be gained from any residual hearing that may exist for the patient.

The specific aims of this research are: 1) to develop an efficient algorithm for detection of the /s/ and /z/ spectral patterns in fluent speech, 2) to develop a practical vibrotactile transducer that fits into an ear module without interfering with normal functioning of an hearing aid, and 3) to develop a wearable, prototype for experimental verification of the concept. These areas are discussed below.

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## SPECTRAL PATTERN DISCRIMINATION

The method that we are developing to detect the presence of a properly articulated /s/ phoneme sound utilizes a measure of spectral similarity. Our problem is somewhat simpler than the more general problem of speech recognition since only a small number of acoustic patterns need to be detected and all others, including background noise, are rejected. In addition, since the device is a monitor, and in some sense a training aid, the patterns of interest can be restricted to a fairly narrow range of acceptable tokens of production.

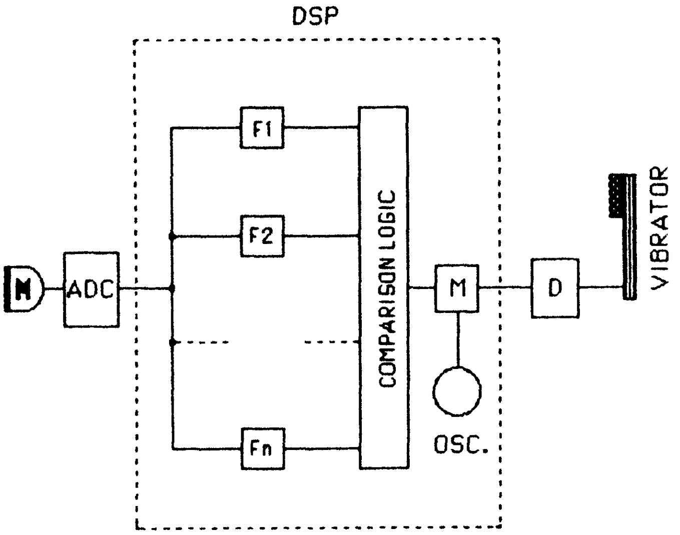

Fig. 1 Functional Block Diagram of /S/-Monitor.

The method that we propose to use is similar to the maximum direction cosine method that has been evaluated by Silverman and Dixon [1]. It will be implemented in the form of idealized filters that represent the spectral character of each acoustic sound of interest. A functional block diagram is illustrated in Figure 1. The gains of each filter is normalized for its particular sound and the comparison logic selects the channel of highest signal energy. If the selected channel corresponds to an /s/ or /z/, the drive to the vibrator is increased to become perceptible. The functional blocks of Figure 1 are currently being implemented on a wearable microprocessor system that is briefly described below.

## VIBRATOR DESIGN

The ear-level vibrator system that has been developed for the /S/-Monitor consists of a small, thin strip of piezoelectric material that is fastened at one end to the inside wall of an ear module and that is loaded at its free end with a mass that results in a natural resonance of about 250 Hz. The arrangement is such that an acoustic channel can pass alongside the transducer and into the tip of the ear module. With this orientation, the vibrator imparts a front-back motion to the ear module.

A mathematical model of the vibrator and skin has been analyzed to determine the optimum design for this vibrator with regard to its size, power and efficiency. These factors are ultimately limited by basic physical properties of materials such as the Young's modulus and piezoelectric coefficient of the vibrator element and the force required to vibrate the skin. It turns out that the vibrator and skin can be modelled as a pair of coupled resonators.

The model for the skin is similar to that of Ishizaka and co-workers [2] and consists of mass, damping, and compliance. If the mass of the ear module is included in the effective mass of the skin this circuit represents the mechanical loading of the vibrator and can be used in determining a near optimal design for the transducer with regard to size and power.

To achieve maximum power transfer to the skin, the vibrator has been designed so that the reactive component of output impedance of the transducer and the reactive component of the driving point impedance of the skin cancel. For a narrow-band device, this is easily accomplished by choosing an operating frequency that is the natural resonance of the skin and by tuning the various other reactive components to resonate at this same frequency. As has been described above, the free end of the cantilevered vibrator is loaded with a mass that is chosen to resonate with the bending compliance of the vibrator at the desired frequency.

The skin resonates at a frequency of around 250 Hz. When the vibrator is tuned to the same frequency of resonance as the skin the equations describing the model are simplified. The displacement of the skin surface is then proportional to the transduction coefficient of the vibrator, the mechanical compliance of the vibrating element and the applied driving voltage. The theoretical sensitivity of the vibrator described above is about 0.8 $\mu$m/volt. Therefore, when driven with a 30-volt signal, a deflection of about 24 $\mu$m should result. This theoretical result has been verified with measured values obtained for the prototype using an artificial mastoid measurement system.

## WEARABLE PROCESSOR SYSTEM

A wearable experimental version of the S-detector device is being developed around a digital processor subsystem that has been described by Engebretson, et al. [3]. This subsystem is contained on a small circuit board and includes a microprocessor, program and data RAM memories and a serial communication port that can be connected to a host computer. Application programs can be downloaded directly to the program RAM memories from a development system. In this way the processor can be programmed in a general way to implement a variety of signal processing models. In our case the processing model is the functional block diagram shown in Figure 1. The serial port of the microprocessor subsystem can be used to change the parameters of the model, such as time constants and filter coefficients.

The analog circuitry that is required for the S-Monitor application, including the driver for the vibrator, has been breadboarded and tested and is expected to fit on a second small circuit board that is connected via a flexible cable to an ear-level unit containing an input microphone, receiver, and vibrator. The size of the body-wearable unit, which includes the processor board, analog board, and battery, is expected to be 5.5 inches long, 3.5 inches wide, and 1.2 inches thick. Design calculations indicate that the battery will provide sufficient power for a continuous period of about eight hours.

## SUMMARY

An experimental monitor device has been described that has the potential for alleviating problems of production of /s/ and /z/ sounds by the deaf and hearing impaired. When finished, the method will be evaluated with hearing-impaired subjects under natural conditions of conversation and background noise. A model for detection of /s/ and /z/ sounds has been described that is being implemented on a wearable microprocessor-based system. In this way important parameters such as time constants and filter characteristics can be evaluated. Preliminary results of these experiments will be presented at the September meeting.

## ACKNOWLEDGEMENT

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