ELCTROMAGNETIC ARTICULOGRAPHY: A BRIEF OVERVIEW

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INTRODUCTION

Up until the development of the first X-ray microbeam at the University of Tokyo the most common and reliable technique to transduce planar articulator motion during speech was cineradiography. As a result of the high radiation dosage the number and duration of such studies was necessarily limited. With the advent of the X-ray microbeam developed at the University of Tokyo [1] the ability to transduce speech articulatory motion with minimal radiation hazard allowed for longer experimental sessions. The expense to construct such a system, however, is considerable and the maintenance and operational costs are much too high to be a realistic consideration for any speech laboratory. Recently alternating magnetic field devices have become a less costly and more widely available alternative [2,3]. The utility of such devices will be outlined below as well as some of the considerations that will affect the sensitivity and reliabillity of the movement reproduction For a detailed evaluation of one of the devices currently in use and limited comparison to other commercially available devices, the interested reader is referred to Perkell, Cohen, Svirsky, Matthies, Garabieta, & Jackson [2].

There are currently three commercially available electromagnetic systems for the transduction of supraglottal articulation; the Carstens Electromagnetic Articulograph (EMA) [3], the Electromagnetic Midsagittal Articulometer (EMMA) [2], and the Movetrack [4]. The principles of operation are similar for all three devices. Transmitter coils, excited by a sinusoidal signal, produce an alternating magnetic field. A transducer coil, oriented parallel to the transmitter and transducer axes, will be induced with an alternating signal whose strength decreases appoximately in proportion to the cube of the distance from the transmitter. All current electromagnetic transduction devices for speech articulation research use monoaxial receiver coils placed on articulator flesh points in the midsagittal plane of the device. The signal induced in each receiver coil is the sum of the number of sinusoids (the number of transmitters) and the sampled voltages are subsequently processed to produce estimates of the distances between the receiver coil and the transmitter. The EMA and EMMA systems calculate the positions in software while the Movetrack system using a hardware implementation to estimate the locations of the receivers. Two of three commercially available systems (EMMA and EMA) use a three-transmitter design in which each transmitter is driven at three different carrier frequencies in the tens to hundreds of kilohertz range.

One of the benefits of the three-transmitter systems is the ability to correct for rotational misalignment between the transmitters and transducers. That is, any receiver misalignment, with respect to the magnetic lines of flux, reduces the estimated distance from the transmitter by the cosine of the misalignment angle. Both the EMA and EMMA systems provide methods for correcting for rotational misalignment while the Movetrack system, using a two-transmitter design, does not allow for any correction. A potential, and highly probable, error condition that neither the two- or three-transmitter systems is able to compensate for is off-midline displacement. Errors due to transducer misalignment with the midsagittal plane vary with position in the recording field [2,5]. Errors due to midline misalignment grow rapidly as a function of increasing distance from the origin of the device. During normal operation a combination of rotational misalignment and off-midline placement (0.5 mm for example) will result in errors ranging from .1 to 1.0 mm [2,5]. Because of the ability to correct for roatational misalignment within certain limits the most critical error factor is midline placement of the receivers in the midsagittal plane of the device.

It is also the case that the three-transmitter systems can operate at a lower field strength compared to the two-transmitter system [2]. For further information on the use of such systems for speech research the reader is referred to a recent publication resulting from an ACCOR workshop on the use of electromagnetic articulography in phonetic research [6].

APPLICATION

In this section a brief overview of the application of electromagnetic articulography to speech research will be considered. Data will be presented that have been collected using a version of the EMMA system [2] housed at Haskins Laboratories. The device has been operational since approximately 1992 following a series of tests to verify accuracy and reliability and to evaluate specific environmental influences [5]. Since the initial studies in our laboratory, the size of the transducers have been reduced by a factor of one-half resulting in receiver coils on the order of 2.5 x 2.5 x 1.0 mm.

A typical experiment consists of the placement of receivers on the bridge of the nose and the maxillary gum ridge (to monitor head motion during the experiment), receivers on the upper and lower lips, the mandibular gum ridge, and four locations on the tongue along with a sumultaneously recorded acoustic signal. At Haskins the nose, maxillary, mandibular, and lip receivers are attached using a biocompatible cyanoacrylate (Isodent). Attachment of the tongue receivers with Isodent requires extensive drying of the tongue surface and because the bonding is broken down by saliva, the attachment times can be quite short. As a result we routinely use Ketac bond to attach receivers to the tongue. . In contrast to Isodent the Ketac bond does not require the same degree of tongue surface drying and saliva has much less of an effect on the bonding of the surfaces. For a typical experiment tongue receivers have remained on the tongue surface for well over 90 minutes.

Signals from the EMMA, the acoustic signal, and any other simultaneously acquired signals (e.g., pressure, electromyographic, glottal transillumination) are digitized on-line (12 bit resolution) using a 64 channel A/D board. Our 10 channel EMMA system requires 30 input channels (3 voltages per channel) since the voltage-to-distance (V-D) conversion is done in software post-acquisition. Off-line calculations solve the near field equation obtaining x-y position of each receiver in the field at each point in time. Additionally, once head and occlusal coordinates have been established all data points are corrected for any head motion and rotated to the subjects occlusal plane.

Because the V-D conversion is done following digitization the voltages can be sampled at any rate that will be supported by the analog A/D board. However, this also means that any receiver problems during an experiment will not be apparent until after the experiment. To eliminate the possibility of wasting time and effort on collecting bad data, Perkell and colleagues at MIT have implemented a real-time display program that runs on a PC and is used to monitor receiver positions during an experiment.

An example of the two dimensional time history data obtained from receivers placed on four locations on the tongue is presented in Figure 1. Shown is a single repetition of a subject repeating the phrase "Say ladder again". The movement trajectories from the tongue have been digitally smoothed (23 point triangular window) following sampling at 625 Hz.

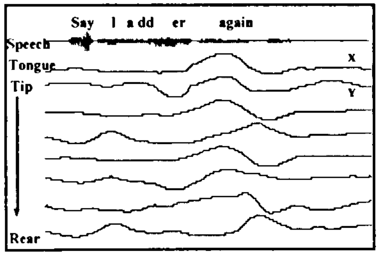

Figure 1. Tongue movement trajectories from four receivers equally spaced from the front of the tongue to the rear spanning a distance of approximately 4 cm.

Shown in the next figure is a single example of a subject repeating the phrase "Say tap again" displaying the motion of the most anterior tongue receiver. At the bottom of the figure is the speed of the tongue tip associated with the two-dimensional trajectory. The dashed line illustrates the movement offset based on a minimum in the speed profile associated with the phonetic segment for /t/ in "tap".

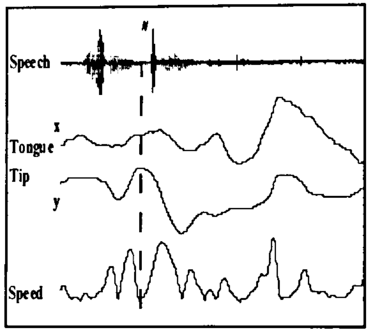

Figure 2. Tongue tip trajectory and the associated speed profile for the phrase "Say tap again". The /t/ closure is associated with the short duration steady state position observed in the tongue tip movement in the Y dimension.

From identification of motion onsets and offsets for a number of repetitions it is possible to acquire mean positions in two dimensional space of the tongue associated with a specific phone. Two dimensional coordinates can be obtained when the speed of the receiver is at a minimum within the acoustic duration of the phone of interest. The data are then fitted using a cubic spline interpolation and an estimate of tongue shape obtained. Figure 3 reflects the average of ten repetitions in which tongue shape was estimated for /r/ in the word "rack" and "heard". Comparing the tongue shape using a cubic spline interpolation with actual shapes obtained from static midsagittal magnetic resonance images have been generally good.

The acquired data can also be displayed as receiver paths in the sagittal plane. Figure 4 is the same data from Figure 1 displayed in this manner in which the form of the articulator paths can be easily visualized. Also presented in the figure is an outline of the hard palate taken during the experimental session. It is also possible to estimate the constriction degree (in the midsagittal plane) by simply locating the minimum distance of a receiver from the palate location at the time of minimum speed .

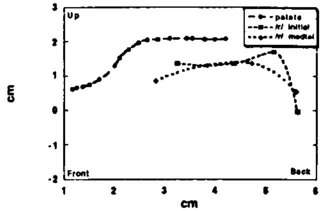

Figure 3. Estimated tongue shape for /r/ when produced word intial ("rack") and syllabic ("heard"). Each points represents the average of ten repetitions with spatial locations obtained at the time of minimum speed for each receiver.

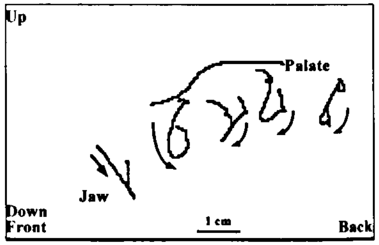

Figure 4. Tongue and jaw paths in occlusal space associated with the word "ladder". Arrows indicate the direction of the motion.

CONCLUSION

Electromagnetic articulography is fast becoming an important tool in the acquisition of large quantities of speech articulation data. Provided that a number of precautions are taken, the precision that can be acheived by such devices can be quite high. While the total costs are often considerable, taking into account the required hardware and software, the acqusition of such devices are within the financial reach of many institutions. Moreover, the use of electromagnetic articulography to clinical populations may provide important breakthroughs in understanding a variety of speech movement disorders [see 7 for example].

With increased use further refinements will be forthcoming in both hardware and software.

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