Electromagnetic Articulography: measuring movements of the tongue, jaws and lips during speech

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Introduction

Researchers who study speech and speech production are interested in the displacements, timing and coordination of articulatory structures inside and outside of the vocal tract. These structures include the tongue, jaws, lips and possibly soft palate.

Conventional imaging techniques like x-ray, ultrasound and MRI have been used to visualize various articulatory structures. However, these devices can be restrictive and invasive. In addition, the tracking of human speech is challenging because speech is characterized by fast, complex 3-dimensional movements of the articulators.

An electromagnetic articulograph (such as the NDI Wave Speech Research System), is a 3D measurement device that is specifically designed to track and record the movements of articulators during speech. It tracks the position and orientation of miniaturized sensor coils that are attached in various places on tongue, jaws and lips. An articulograph records articulator trajectories directly, without the need for complicated post-processing of individual images.

Electromagnetic tracking is fast, accurate and safe for subject and operator. The strength of the electromagnetic field that is generated is comparable to the electromagnetic field generated by a conventional hair-dryer. There is no harmful ionizing radiation.

How does an electromagnetic articulograph work?

An electromagnetic articulograph is a position measurement system that tracks the position and orientation of miniaturized sensor coils.

An external field generator (FG) generates a slowly modulating magnetic field that evenly propagates through human tissue and couples to the sensor coil. The voltage induced in the sensor coils by the alternating magnetic field is recorded and translated into position and orientation data.

The physical principle behind electromagnetic tracking is the ‘inverse cube law’: for two coils with their long axes oriented in parallel (one generating and one sensing coil), the voltage induced in the sensor coil is inversely proportional to the cube of the distance from the generating coil. The ‘inverse cube law’ was first described in the second edition of Newtons’ Principia (published in 1713). It was confirmed experimentally by Thomas Le Seur in 1742.

The first account of electromagnetic tracking in speech research was by Thomas J. Hixon in 1971.
In the past, articulographs could only measure movements in 1 or 2 dimensions and were sensitive to coil misalignments.

Modern articulographs have overcome these limitations by using multiple generating coils and performing misalignment corrections. Now sensor coils can move freely relative to the field generator. Their position and orientation is tracked at high speed and spatial resolution.

Due to the physical nature of electromagnetic fields, electromagnetic articulographs are inherently sensitive to electromagnetic distortions (by electronics, motors, ferrous metal, etc.). For the best results, measurements are conducted in a ‘clean’ environment, without exposure to elements that may cause distortions.

Experimental setup

A typical speech-experiment using an articulograph takes 4 steps:

1) The articulograph hardware and microphone are connected to a computer with the appropriately installed software and drivers.
Some articulographs require cleaning and calibration of each individual sensor before every experiment. NDI Wave sensors are pre-calibrated and disposable.

a. The subject is prepared for the experiment – 5DOF sensors are applied inside and outside of the vocal tract.

Source: University of Groningen, School for Behavioural and Cognitive Neurosciences (Netherlands), March 2014

b. If desired, a 6DOF reference sensor is applied (usually on the head or maxilla)

Penn State, Dept. of Communications Sciences and Disorders, Speech Production Laboratory (USA), May 2015

c. An anatomically meaningful coordinate system is defined by aligning the reference sensor or specifying anatomical landmarks/bite plane.
d. If desired, the palate is digitized.

2) The subject participates in 20 minutes of warm-up exercises to adjust to the articulograph sensors and cables.

3) The experimental protocol and data collection commences.

Articulograph data and data processing

The articulograph records kinematic data: three translational coordinates (x, y and z) and two or three rotational coordinates of sensor coils relative to a reference coordinate system. The number of rotational coordinates the system can detect depends on the type of sensor coil used: 5 degree-of-freedom (DOF) sensors or 6DOF sensors.
5DOF sensor coils are very small but lack rotational information around their long axis. 6DOF sensors are usually bigger because they contain more than one coil. Because their location and orientation in 3D space is fully determined, the 6DOF sensor can function as a reference coordinate system.

Head movement correction

If a sensor coil on the tongue moves closer towards the field generator, is it because the tongue moved relative to the head, or because the head moved relative to the field generator? In most speech studies, only the movement of the tongue relative to the head is of interest. In those cases, a 6DOF sensor is attached to the upper jaw (maxilla) or head (the bridge of the nose, for example) to provide a head-based reference coordinate system. Expressing movement of the articulators in a head-based coordinate system (rather than a field generator based coordinate system) is called head movement correction.

Data rotation

If the data is recorded in a coordinate system that is not ‘anatomically meaningful’ it is rotated into a more meaningful coordinate system through mathematical operations. An anatomically meaningful coordinate system can be defined by digitizing anatomical landmarks or by establishing the bite plane with a bite plate.
Palate tracing

Any structure that doesn’t move relative to a 6DOF reference sensor can be localized as (an array of) digitized points relative to the 6DOF sensor. The boney part of the palate does not move relative to the maxilla/ head. It is a relevant structure in speech production and hence, often digitized by tracing a sensor or probe along its surface. Once the position and shape of the palate is mapped, the position of the sensors can be analyzed in relation to the palate.
Synchronization with Audio

Speech is characterized by speech movements and speech sounds. Therefore, articulograph data is usually recorded in conjunction with audio data. From the synchronized data, researchers can extract articulatory positions and format frequencies at specific points in time. They can look at acoustic variables, such as the energy in a particular frequency band, and derived kinematic variables, such as velocity and accelerations. Researchers can study the timing and patterns of articulatory landmarks and how movement and sound relate to each other.

Real-time feedback

Articulograph data is available to third party applications in real-time and can be used to provide instant feedback about the movement of the articulators to the speaker and/or researcher. Real-time feedback is becoming more and more important for researchers who are interested in speech pathologies, accented speech, etc.

The NDI Wave Speech Research System not only displays real-time data but also streams it over TCP/IP so that it can be accessed by a wide range of applications for immediate processing.
Conclusion

The research of human speech has unique technological challenges. Tracking the fast and complex 3D movements, which occur inside and outside the vocal tract during speech, requires a specialized device called an articulograph. Over the years, electromagnetic articulographs have evolved from custom-built 1D and 2D tracking systems with large coils and stringent constraints on coil orientations to commercially available 3D tracking systems that track freely moving, miniature coils in real time.

As a result of these advances, articulographs (such as the NDI Wave Speech Research System) provide researchers with the means to study speech and speech production in a way that is safe, non-invasive, and accurate.