DEVELOPMENT OF A SYSTEM FOR THREE-DIMENSIONAL FLESHPOINT MEASUREMENT OF SPEECH MOVEMENTS

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ABSTRACT

EMA systems have provided invaluable information on speech kinematics. Existing systems restrict the measurement area to the mid-sagittal plane of the subject and are therefore unable to track lateral movements of the tongue. They place severe restrictions on subjects' freedom of movement and thus potentially compromise the naturalness of their speech. We are developing a new EMA system that derives not only three-dimensional spatial coordinates, but also the orientation of the sensors. We briefly review the mathematical background and report on the development process. We were able to develop a new digital-featured device. We discuss initial measurement results and give an outlook on the next steps to be taken.

1. INTRODUCTION

Existing electromagnetic mid-sagittal articulography (EMA) Systems have provided invaluable information on speech kinematics, especially for the tongue.

Two main drawbacks remain, however. Firstly, phonetically relevant tongue movements are of course inherently three dimensional. Secondly, great care must be taken to ensure that the measurement plane of the apparatus and the mid-sagittal plane of the subject remain in alignment. This places severe restrictions on subjects' freedom of movement and thus potentially compromises the naturalness of their speech.

A related problem is that substantial lateral deviations of the tongue from the midline cannot be captured without error.

Accordingly we started the development of a new electromagnetic articulography system, which is able to acquire data within a cubic or spherical area without further restrictions.

2. THE 3-D EMA-SYSTEM

2.1. Theoretical background

2.1.1. EMA-Basics. EMA-Systems operate with EM-field generating coils which one can regard as antennas for very low frequency radio waves. Actually the waves differ in some points from regular radio waves i.e. they do not interfere with most matter, are semi-stationary and do not interfere with each other.

All EMA-Systems are determined by the fact that the field generated by a coil has dipole character and that the received signal becomes zero when transmitter and receiver are perpendicular to each other.

Thus, the signal varies not only with distance between transmitter and receiver coil, but also with the angle between transmitter and receiver axis. While the first effect yields the calculation of the distance through the “one over cubed distance”-formula, the second is most unwanted and results in the restriction to a planar measurement area.

2.1.2. How 3-D-EMA works. As mentioned before a receiver-coil is a kind of dipole and therefore has five degrees of freedom. These are the three X, Y and Z co-ordinates and the 2 angles that describe the alignment of the dipole.

In order to determine the position in a three dimensional area, all five values must be known. Furthermore, the system should be able to measure all directions with the same efficiency.

This is realised by the spherical placement of six transmitter coils. Thus there is between every two transmitter coils a right angle; the placement is absolutely symmetrical. Each coil indicates a value, therefore, in mathematical terms, we have a set of six equations with five unknowns.

When aligning the transmitter coils one should consider that the induced voltage becomes zero when the transmitter and receiver axis are perpendicular. In this case, no information is available concerning the distance between transmitter and receiver.

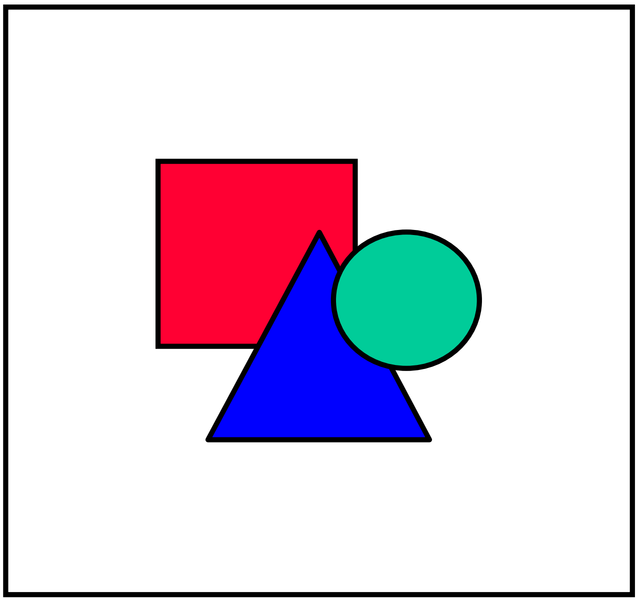

Fig. 1: Spherical placement of the 6 transmitter coils.

Therefore the alignment of the transmitter coils has been chosen so that the receiver, regardless of how it is turned, is never perpendicular to more than three transmitter coils at one time.

2.1.3. Calculating the position. Each transmitter coil induces a signal into the receiver which is a function of the relative position and alignment of transmitter and receiver. On the other hand five values are necessary to describe position and alignment of a coil as already mentioned.

So, for every measurement point a set of 6 equations must be solved in order to determine the position of the receiver coil. Because the field equations are not linear the solution must be computed numerically. Therefore a modified form of the Newton-algorithm is used. This algorithm calculates the numeric solution of n-dimensional equations.

Because we have an overdetermined system with 6 equations and 5 variables, the standard Newton-method is merged with the Householder-Transformation, which is used to estimate the solution of an overdetermined linear equation set.

To treat both translation and rotation co-ordinates in the same way, a projection is applied to the two angles. It transforms the two angles, which define a point on a sphere, to a point on the projective plane.

The result is transformed back to positional and alignment co-ordinates of the sensor.

2.2. Technical realization

2.2.1. New concepts. When it came to the technical realization, we decided against an improvement of the Carstens AG100, as far as the signal processing components are concerned. We do use the AG100's amplifier circuits and the transmitter coils and resonance circuits (with minor changes) due to their well known electrical properties.

Because of the massive evolution in the field of Personal-Computers and digital signal-processing, we were able to develop a new digital-featured device. So we reduced the proportion of analog circuits to the absolute minimum, aiming to receive more flexibility in the area of signal processing.

With a digital system the algorithm is coded in software rather than in custom circuits. So the system can be easily speeded up as soon as faster computer chips become available.

Another advantage of this new design is that it will be possible to change the algorithm after the development phase without redesigning the hardware, e. g. with more experience in collection of 3-D data. A good example for this is the demodulation of the sensor signal.

While the AG100 uses an analog circuit to obtain the amplitude of each transmitter signal, we are just pre-amplifying the sensor signal and then perform an A/D-conversation. Now we can test several approaches to demodulation of the raw signal, using standard components like MATLAB Scripts. The AG100 mechanism was phase sensitive, so it always took some time to calibrate the device until the signals were in phase. We use an algorithm based on digital data that is not affected by any phase lag and therefore get a much easier calibration-sequence.

The separation of the algorithm from the underlying hardware also gives us major advantages during the development cycle, since both parts can be developed in parallel [3]. This matters since the 3-D articulograph is more complex then it's 2-D predecessors, so it is vital to split development into clear units.

2.2.2. The new 'helmet'. Fig. 1 shows schematically the placement of the 6 transmitter coils in principal. Since the new 3-D EMA system has no preferred measurement plane, the structure can be rotated to fit the subjects head within.

Fig. 2 shows the final coil mounting structure for the 3-D EMA in a side view with 4 of the 6 transmitter coils visible. The structure is build from 2 triangles with a transmitter coil on each vertex. Not only is this a very straightforward design, but also a mechanically robust structure.

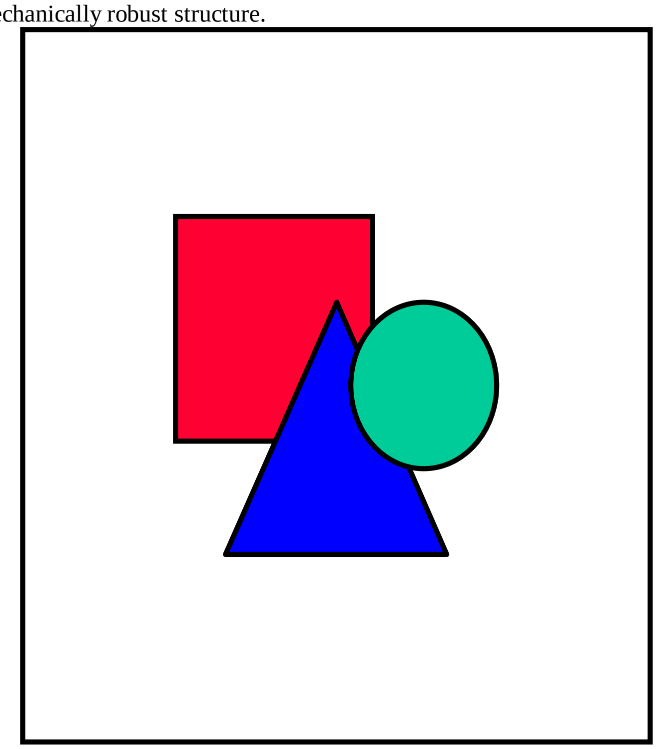

Fig.2: Final coil mounting structure for the 3-D EMA.

2.2.3. Transmitter Device. We are using a regular PC to drive the 6 transmitter coils. It is equipped with a fast Digital IO-card from National Instruments and runs a program which generates 6 sinusoidal signals with different frequencies in real-time.

Fa. Carstens, who build the commercial EMA-System AG100 provides the still necessary custom hardware. This comprises a custom QSPI-fast-serial interface, a separate device with D/A-Converters, power-amplifiers and the resonant circuits along with the transmitter coils.

We have a preliminary structure to mount the 6 coils, but a more suitable structure is already under construction.

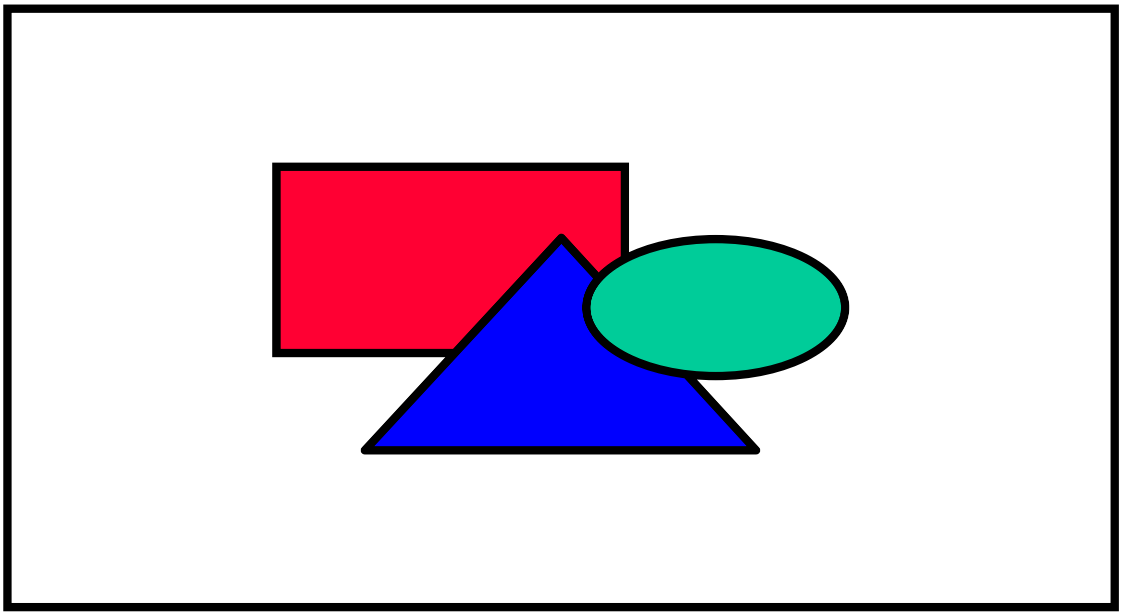

Fig.3:Schematic diagram of the components of the 3-D articulograph.

2.2.4. Receiver-PC and data-processing. The receiver operates with regular monoaxial receiver coils, due to their low costs and small dimensions. The pre-amplified signal is digitized by a National Instruments Multi-I/O-card, which is part of the Receiver-PC and written to disk.

It is planned to use this second PC for real-time data-preprocessing and to use a third PC for position-calculation and analysis of the data.

So at the moment we are using up to three PC's on a Windows-NT platform to perform data acquisition and analysis and a fourth PC to move the receiver coil on a predefined path (see section 2.3).

It is obvious that the device is not very 'handy' at this stage of development, but there are multiprocessor PC's available by now so we will be able to reduce the number of separate computers.

2.3. Initial measurement data

Since February 1999 the preliminary device has been ready to go and we started the collection of measurement data. A receiver coil is moved by a three-axis motor controller on a well defined path and data is collected at equidistant points.

The resulting signals are de-modulated and serve as input data for the position-calculating algorithm. Finally the calculated positions can be compared with their desired values. Since all parts of the system have very open interfaces at the moment, we are also able to analyze raw data along with several intermediate results of the algorithm.

The very first results of these studies let us qualitatively reconstruct the shape of a given receiver path, but do not allow statements of reliability in terms of position-error. This is because several parts of the system (both hard- and software) operate under test-conditions now and a lot more data is needed to track the cause of occasional bad data and to verify the state of the new digital components.

3. OUTLOOK

In the near future we will focus on the position calculating algorithm. Results to date have been that measured amplitudes differ from calculated ones in a systematic way. We are probably faced here with a situation that is familiar from the old 2-D system, where, as shown in Hoole [1] and Kaburagi & Honda [2], it is actually quite an intricate task to derive a voltage-to-distance relation that is equally valid for all parts of the measurement field. If this applies for the new system too, we will have to take some efforts to 'tune up' our mathematical model.

One of the first tests planed with human subjects will be the compensation of head movements during the measurement. Looking at the head as a rigid body, with only two reference sensors it should be possible to track any movements of the head and to transform tongue-movement data into a skull-based co-ordinate system. This feature enables subjects to move their head freely while under study and should therefore provide a more natural experimental situation.

ACKNOWLEDGMENTS

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