EMA AND THE CRUX OF CALIBRATION

Andreas Zierdt

Institute of Phonetics and Speech Processing, LMU, Munich
andreas.zierdt@phonetic.uni-muenchen.de

ABSTRACT

Electro-**M**agnetic-**A**rticulography has been a well-established technology for many years The new AG500 System even allows the investigation of articulatory movements in three dimensions. Still, calibration is a crucial point to obtain reliable and accurate data. After a short glance of the mathematical background and a review of previous methods, the present *Circal* device is discussed. Due to its construction a basic calibration problem probably remains, since the Circal neglects sensor orientations outside of the x/y-plane. Depending on the sensors actual position and orientation, a suboptimal calibration can have a mild or dramatic influence on the position calculation, which might even fail. Several approaches are thinkable to overcome the calibration problem, three types are discussed, which can be characterized as mechanical, physical, and mathematical solutions. Finally the actual work on a mathematical solution is briefly presented.

Keywords: **E**lectro-**M**agnetic-**A**rticulography, EMA, AG500, articulatory measurement system.

1. INTRODUCTION

Electro-**M**agnetic-**A**rticulography (EMA) is a well-established technology for the investigation of articulatory movements of tongue, jaw, lips, etc.

Small sensor coils are attached to the subject and an array of transmitter coils induces VLF[1] signals into the sensors. Since the induced signals vary with distance and alignment to the transmitters, the sensor position can be determined ([2] gives a more detailed description).

Due to the point-tracking nature of EMA, velocities and accelerations of selected points can be more easily observed, than with imaging techniques.

Over the last few years, the five-dimensional system AG500 of Carstens Medizinelektronik GmbH has become quite popular, as it allows not only full spatial recording of sensor movement, but also measurement of the sensor orientation.

As already with the previous two-dimensional EMA-Systems, a calibration procedure has to be carried out periodically to ensure optimal accuracy of the device and to cope with erosion of the sensors.

This paper deals with calibration of the AG500, aiming to show intrinsic problems of the methods used so far and to present a new approach.

2. ON CALIBRATION

Assuming a proper field model, one can calculate the relative change of signal amplitudes as a function of sensor position and orientation. But, since the signal path involves several amplification steps, quantization, and receiving sensors that are subject to erosion, obviously one can not calculate absolute amplitudes (e.g. in Volt).

For purposes of sensor tracking, yet the absolute measured signal strength is not important, but the position calculation algorithm heavily depends on comparing measured and expected signals.

So, a special calibration measurement has to be performed, before the system can be used.

Each of the 12 channels of the AG500 has 6 calibration factors (for the six transmitters) which have to be determined close to the time of any measurement session. Any change of a sensor will invalidate the calibration.

2.1. Mathematics

The induced signal U for a given sensor is proportional to the cross product between its axis o and the magnetic field vector H, which itself is a function of space.

(1) $$U(\vec{p},\vec{o}) = C \cdot \vec{\mathrm{H}}(\vec{p}) \cdot \vec{o}$$

The constant of proportionality C covers all effects of quantization and amplification and everything material specific.

On the left side of Eq. 1 stands the measured signal as observable, while (on the right) the distribution of the magnetic field H can be described by a proper field model function, giving the expected or calculated signal.

Therefore C can be expressed as quotient of the measured and expected signal amplitude:

$$C = \frac{A_{measured}(\vec{p},\vec{o})}{A_{calculated}(\dot{p},\dot{o})} \quad (2)$$

2.2. Calibration methods

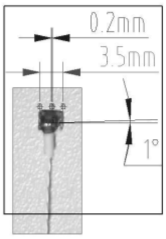
Even if all present AG500 systems are using the Circal device for calibration, a short review might be appropriate to illustrate the core problem.

2.2.1. Static calibration

As stated above, in theory a calibration can be performed by bringing each sensor to a known position and orientation, and calculating the quotient of measured and expected signal.

Indeed, this was tried at the beginning of development, but it soon turned out, that the required mechanical calibration accuracy could not be achieved. It was simply impossible to determine the sensor position with an error less than 1/30 of the sensor size, not to speak of properly aligning it.

Figure 1: Sensor and measurement accuracy. For a static calibration, the sensor would have to be placed much more accurate, than this.



2.2.2. Autokal device

To overcome the problem of exactly placing the sensor, the Autokal[2] device was invented. To perform the calibration, the sensors were moved to different positions. Even if the exact origin was unknown (as before), the relative movements were highly precise. To find the calibration factors one had now to solve an equation system, which also yields the origin p_0 as part of the solution.

One drawback of the device was that it could only translate the sensors, not rotate them. We found that we got different calibration factors, depending on the orientation of the sensors during the calibration. We found also, that measurement accuracy decreased when the sensor turned away from the calibration orientation during a recording session.

There were many possible explanations for this: Spatial magnetic distortion by extra fields, inadequate field model, or mechanical errors of the calibration device or even the transmitter array. Elaborate tests were performed, but none of them appeared to be the crucial factor ([3], [4], [5]).

It turned out, that the problem lies in the calibration equation itself. If we transform Eq.1 for the calibration, we get:

$$Amp_i = \vec{H}(\vec{p_0} + \overrightarrow{\Delta p_i}) \cdot \left(\vec{o} \cdot C\right) \quad (3)$$

Since only *Dp* changes during the calibration, the algorithm can not compute the real sensor orientation, but has to take the provided value.

As a consequence it can only partly compensate the sensor orientation and computes products of calibration factors and orientation aberration.

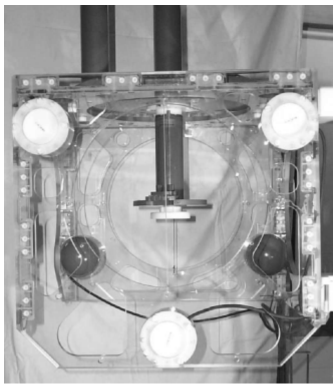
When operated in the calibration orientation, the two errors of assumed orientation and wrong calibration factor compensate each other, but different sensor orientations will cause effective errors in computed positions.

2.2.3. Circal device

The Circal device which was introduced in 2004 does rotate the sensors during calibration.

It consists of a disk on which the sensors are mounted for calibration. The disk hangs into the measurement area and can be rotated by a motor to produce a set of measurements.

Figure 2: Circal calibration device, a revolvable disk moves and rotates the sensors in the x/y-plane.



Due to its construction, Circal rotates the sensors only in the x/y-plane. The spatial sensor orientation can be described by two components, i.e. two flat angles.

According to this, there is one component that moves and one that does not and probably the problem shown in Eq. 3 is just alleviated, but yet not solved.

During normal operation of the AG500, we often notice problems of the position calculation, that occur when the sensor orientation becomes parallel to the z-axis. This strengthens the idea of a remaining calibration problem.

2.3. Consequence of a suboptimal calibration

To understand the consequences of a suboptimal calibration, a short digression is needed.

2.3.1. Characteristics of the field distribution

The magnetic field intensities of the AG500 can be described by a dipole approximation, meaning they are cubically decreasing with distance. Eq. 4 gives the formula in polar coordinates:

$$f(j, J, r) = \frac{1}{r^3} \cdot \sqrt{1 + 3\sin^2(J)} \tag{4}$$

Beside of the field intensity, the measured signal depends on the scalar product (see Eq. 1) of field vector and sensor axis. With ß as opening angle between field vector and sensor, we obtain:

$$Signal = C \cdot f(j, J, r) \cdot \cos(b) \tag{5}$$

This function hast two important features:

- it can become very steep ($1/r^3$)
- it changes sign and crosses zero (cos ß)

2.3.2. Position calculation with Newton's method

Figure 3: An example of Newton's Method for a one-dimensional case.

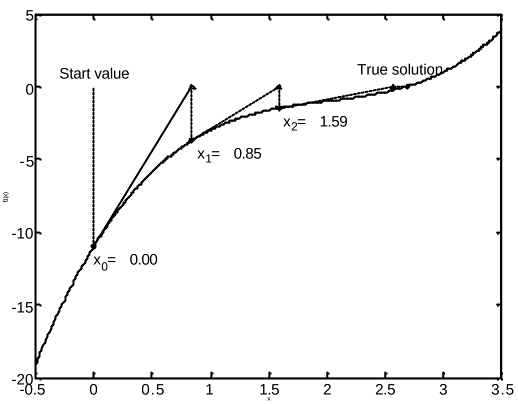


Figure 3 illustrates the Newton method, which is used during position calculation to numerically solve complex equations (as Eq. 5) by iterative linear approximation, based on the functions derivative.

The accuracy (x-error) of a point is proportional to the residual (y-error) divided by the local derivative.

2.3.3. Conclusion

The effect of a wrong calibration is to multiply the signal (as in Eq. 5) with a factor, thus adding an offset to its derivative.

Depending on the sensors actual position and orientation, this can have a mild or dramatic influence on the position calculation, which might even fail.

Due to the dipole character of the used magnetic fields, accuracy of EMA is not constant over space and neither are the effects caused by suboptimal calibration.

The prevailing calibration procedure with the Circal device is probably no optimal solution, since it neglects sensor orientations outside the x/y-plane.

2.4. A NEW APPROACH

Since calibration seems to be the most critical part of EMA, the question is: How it can be improved?

2.5. Thinkable solutions

Several approaches are possible, each with it's own drawback.

2.5.1. 'Clockwork'-Calibration

The direct conclusion from the aforesaid could be to build a new calibration device, that allows rotation on two axes. This could indeed solve the problem, but it is not easy to imagine, how to build such a mechanical construction, with the required accuracy and without the use of metal.

Probably such a 'clockwork' would be quiet expensive and also difficult to handle.

2.5.2. Helmholz calibration

In theory, it is possible to perform the calibration without moving the sensor at all. Three Helmholz pairs with perpendicular axes would allow generating a spatially uniform magnetic field, where the field vector could be electrically rotated until it is parallel to the sensor axis.

The field of Helmholz coils can be exactly calculated and so they are well suited for calibration purposes. Also calibration would only take a second.

Even if this would be an elegant solution, it would still require some additional development work. Helmholz coils are relative big, so the device would also not be very handy.

2.5.3. Deviceless calibration

As was said earlier, the aim of calibrating the sensors is not to measure signals in Volt, but to make the position calculation algorithm (*TAPAD*) work. In the other way round: If TAPAD produces good results, the calibration is correct.

So, if we can define appropriate quality measures, calibration can be performed without a special device and even without a specific calibration measurement by means of optimization or simulation procedures.

Hoole [1] already used a method to adjust the originally measured amplitudes by the predictable component of the amplitude residual. Another approach will be presented in the next paragraph.

Deviceless calibration certainly provides an attraction, because it shifts the whole effort of calibration into the domain of mathematics and programming. Drawbacks here are growing complexity, long computing time, and a certain self-referentiality, which might lead in the wrong direction.

2.6. 'DisCal' – calibration by chance

Recently we worked out a calibration method based on a Monte Carlo simulation. First a measurement is performed, where a magazine with 4 sensors is moved and rotated randomly for about 10 s. The data is than processed by TAPADM to gain sensor positions for each channel.

For every measured point the Euclidian distances between the sensors are calculated. The variance of the distances is analyzed with a statistically robust measure (*Inter Quartile Range*).

The IQR values are merged to a value that describes the variance of one sensor relatively to all others during the measured trial.

Next the calibration factors are randomly changed and the whole calculation is repeated.

Over time we found calibration factors with better (smaller) variance, as shown in **Table 1**.

Table 1: Variance of the distances (IQR) for positions (in mm) and sensor-pair orientation gap (in °) depending on calibration factor found by circal or discal.

Sensor pair	Pos. (circal)	Pos (discal)	Orient. (circal)	Orient. (discal)
1-2	0.69	0.63	0.21	0.17
1-3	1.44	1.26	0.39	0.36
1-4	1.74	1.14	0.39	0.28
2-3	1.23	0.64	0.54	0.26
2-4:	1.19	0.74	0.23	0.21
3-4	1.97	0.69	0.42	0.16

The calibration factors found by *discal* are resulting in a much smaller variance of the sensor distances than after the regular *circal* calibration.

The discal-variant shows also smaller variance of the total error range but due to the great influence of outliers, the effect is not so clear. At the moment it is little more then a proof of concept, but obviously the calibration factors calculated by circal are not optimal. Since we know that the spatial accuracy of the AG500 heavily depends on proper calibration, the present findings are justifying further analysis.

3. REFERENCES

[1] Hoole, P. Zierdt, A. 2006 *Five-dimensional articulography*, Stem-, Spraak- en Taalpathologie 32.8310/Supplement/1406-i Vol. 14, , Supplement, pp. i-ii Nijmegen University Press

[2] Zierdt, A.; Hoole, P.; Tillmann, H.G. 1999 *Development of a System for Three-Dimensional Fleshpoint Measurement of Speech Movements*. Proc. ICPhS 1999. San Francisco. August..

[3] Zierdt, A. http://www.phonetik.uni-muenchen.de/~andi/EMAPage/Archives/Disk22.pdf, visited 5-Mar-2007

[4] Zierdt, A. http://www.phonetik.uni-muenchen.de/~andi/EMAPage/Archives/Disk22Rep.pdf, visited 5-Mar-2007

[5] Zierdt, A. http://www.phonetik.uni-muenchen.de/~andi/EMAPage/Archives/StraightLinieAnalysis.pdf, visited 5-Mar-2007

[1] Very low frequency (VLF) is the name of radio frequencies in the range of 3 to 30 kHz.

[2] Autokal stands for ‚automatic calibration', since previous calibration devices for 2D systems required manual movement of the sensor.