Geometric Calibration of Acoustic Camera Star48 array

Christian Manthe

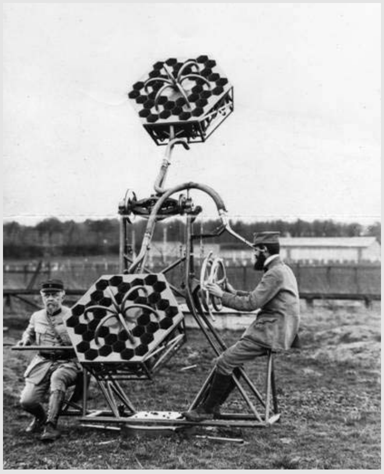
Institute for Geodesy and Geoinformation Science
Technische Universität Berlin, Germany

Early analog "Acoustic Cameras"

Devices to improve the human sense of hearing.

Used to locate sound emitting objects.

"Topophon" (1880) by
Prof. A.M. Mayer



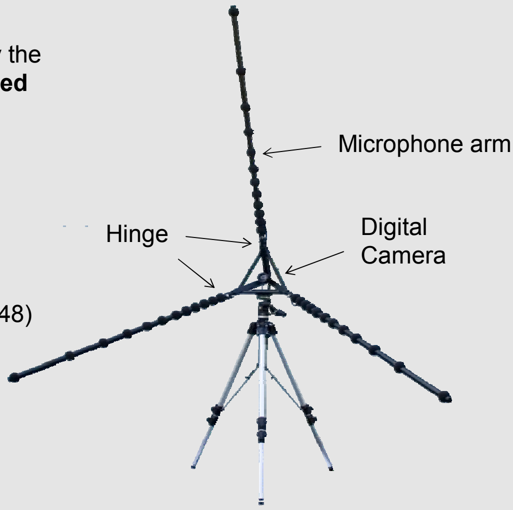
Hexagonal Array by Jean Baptiste Perrin (determine direction of aircrafts in WW I)

Source: (C) AIP Niels Bohr Lib.

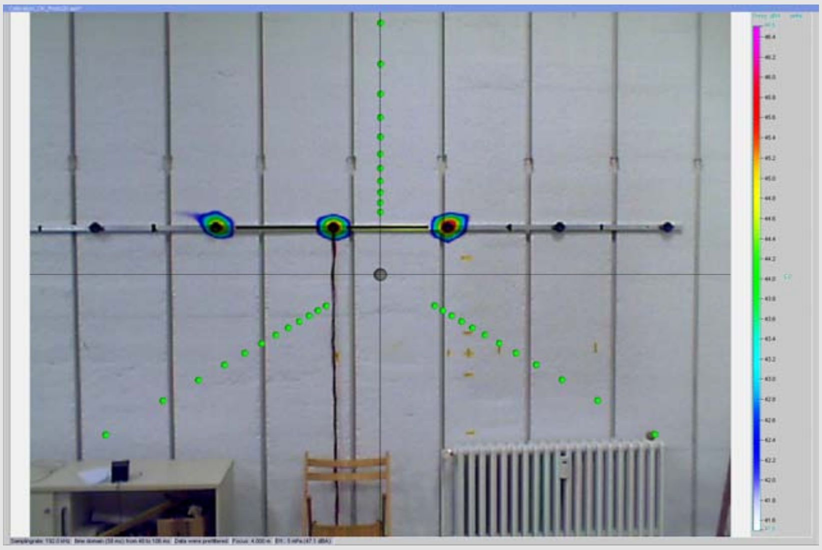
The Acoustic Camera:

Acoustic Camera were developed by the **Society for the Promotion of Applied Computer Science GFaI** .

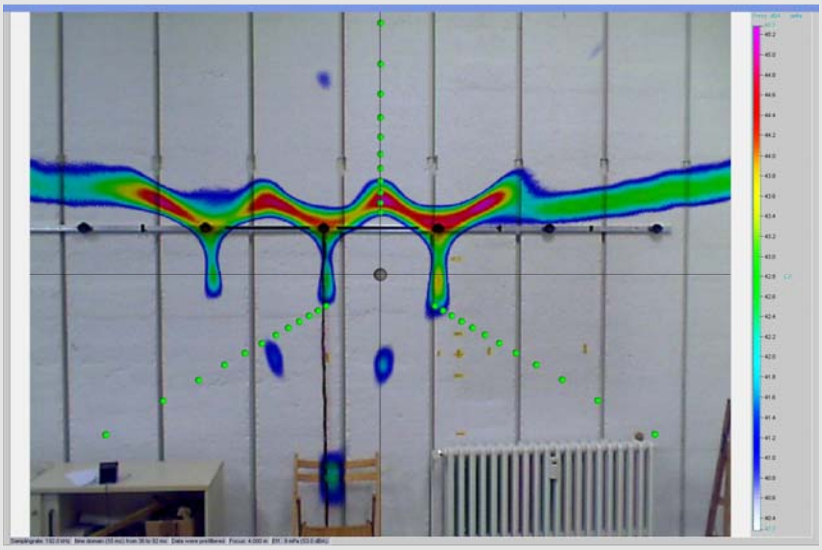
- Portable system
- fixed on a tripod
- size about 3 m
- 3 microphone arms
- on each arm 12 (star36) or 16 (star48) microphones
- a digital camera in the center
- data recorder to collected the data



Sound pressure image

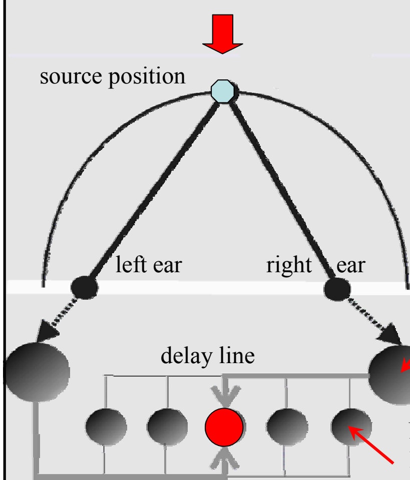


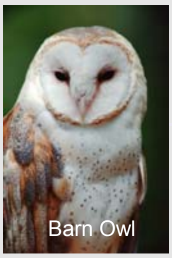
Sound pressure image before calibration



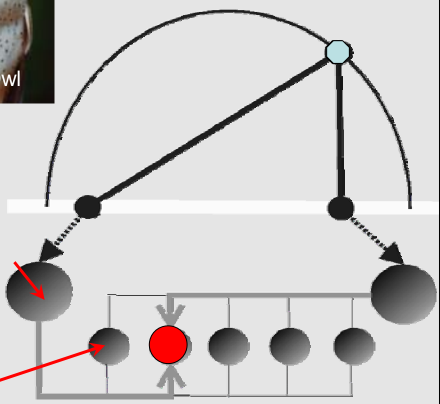
Time Delay in the Brain

Localization Model by
L.A. Jeffress (1948)





Barn Owls use this techniques to hunt animals in the dark.



Create a sound pressure image

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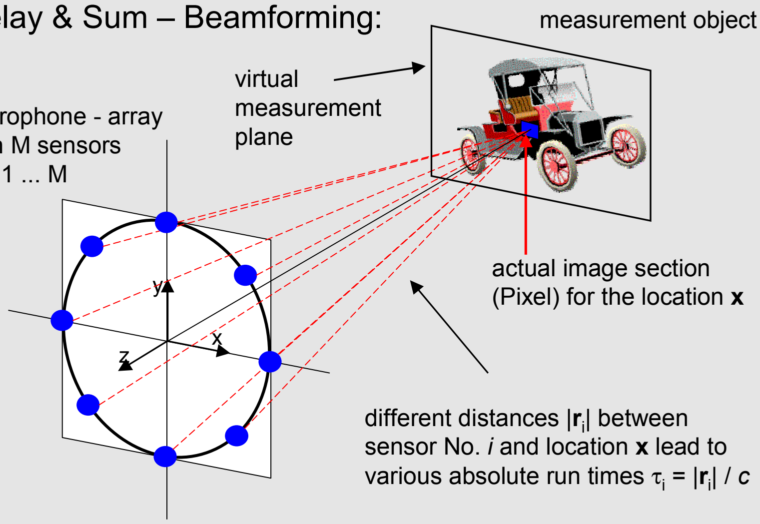
Delay & Sum – Beamforming:



different distances $|\mathbf{r}_i|$ between sensor No. i and location **x** lead to various absolute run times $\tau_i = |\mathbf{r}_i| / c$

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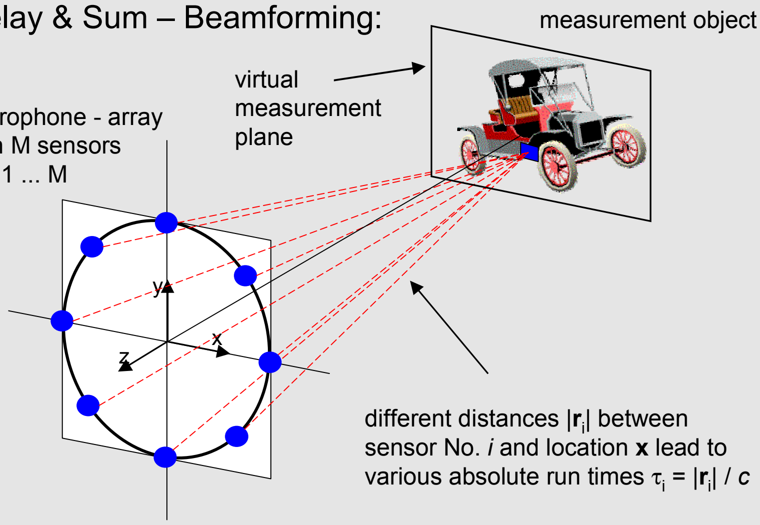
Delay & Sum – Beamforming:



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Create a sound pressure image

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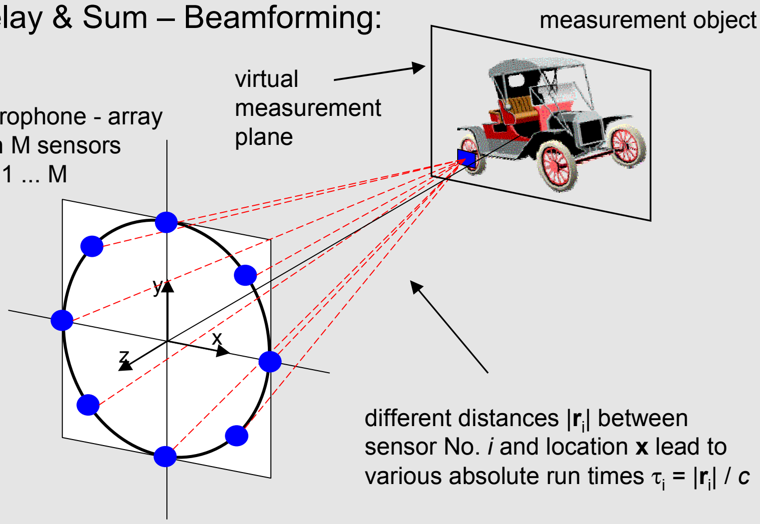
Delay & Sum – Beamforming:

microphone - array
with M sensors
i = 1 ... M



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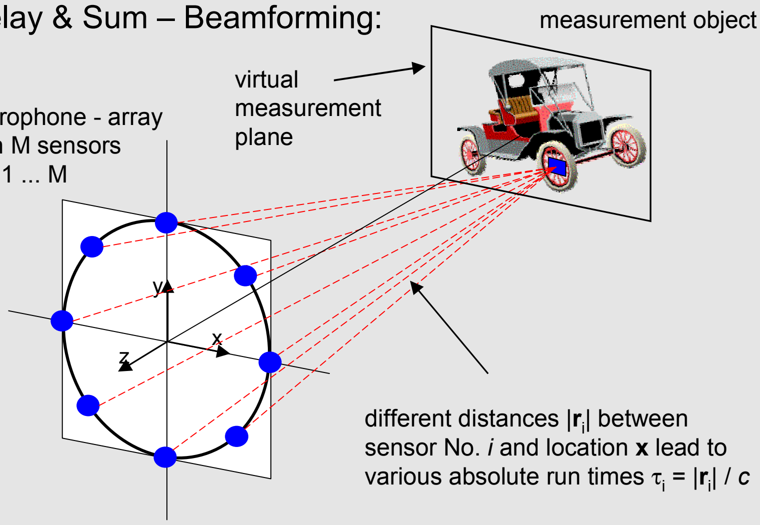

different distances $|\mathbf{r}_i|$ between sensor No. i and location $\mathbf{x}$ lead to various absolute run times $\tau_i = |\mathbf{r}_i| / c$

Principle of the acoustic camera

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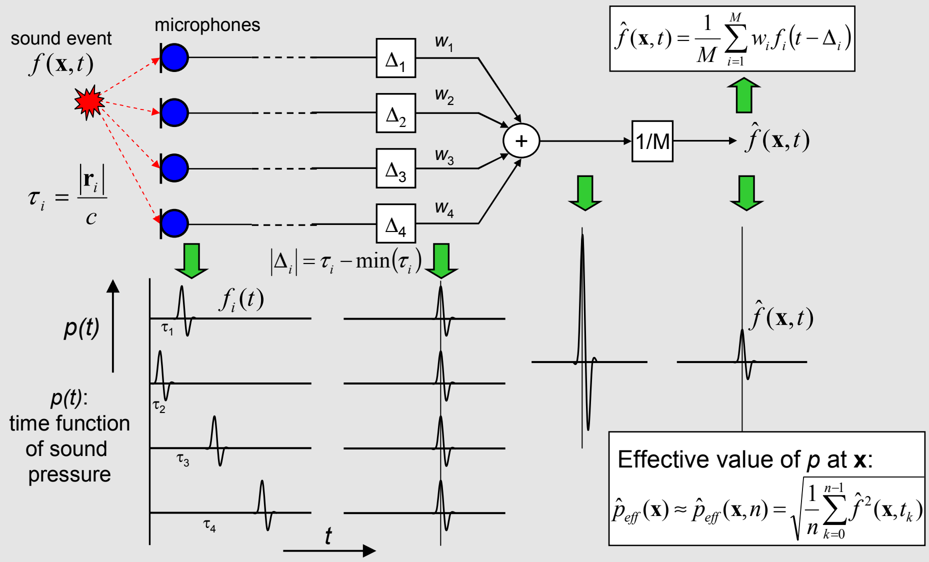

Tasks?

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- The resolution of the sound pressure image is influenced by the precession of the relative positions of the microphones.
- Inaccurate coordinates of the microphones implicate inexact time delay sets. Which results in smudgy sound pressure images.

task:

- Localize the microphones with height precision
- Calculate **residuals** to calibrate acoustic software

General workflow

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Firstly:
Geometric coordination of the microphones in the (left hand) measurement system.

Secondly:
Transform the calculated coordinates into the (right hand) camera system to calculate the residuals

Measurement Design

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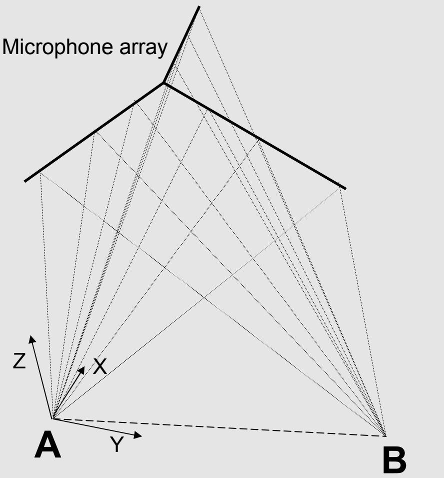
Basically we used an intersection of zenith and horizontal directions.



Observations:
- zenith angles (±0.3mgon)
- horizontal directions (±0.3mgon)
- slope distance AB (±1mm)
- a priori known distances (±0.1mm)

Parametric adjustment

- adjusted observations
- Precision of the observations
- local coordinates of the microphones
- Precision of the coordinates
- statistic values

Measurement devise
Leica TCA 2003

Measurement Design

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Observations equations

$$r_B^{mic} + v_{i+n} = \arctan\left(\frac{y_{mic} - y_B}{x_{mic} - x_B}\right) - \omega_B \qquad r_A^{mic} + v_i = \arctan\left(\frac{y_{mic} - y_A}{x_{mic} - x_A}\right) - \omega_A$$

$$r_B^{A} + v_{2+2n} = \arctan\left(\frac{y_A - y_B}{x_A - x_B}\right) - \omega_B \qquad r_A^{B} + v_{1+2n} = \arctan\left(\frac{y_B - y_A}{x_B - x_A}\right) - \omega_A$$

$$\vartheta_A^{mic} + v_{i+2n+2} = \arctan\left(\frac{\sqrt{(y_{mic} - y_A)^2 + (x_{mic} - x_A)^2}}{z_{mic} - z_A}\right)$$

$$\vartheta_B^{mic} + v_{i+3n+2} = \arctan\left(\frac{\sqrt{(y_{mic} - y_B)^2 + (x_{mic} - x_B)^2}}{z_{mic} - z_B}\right)$$

$$\vartheta_A^{B} + v_{1+4n+2} = \arctan\left(\frac{\sqrt{(y_B - y_A)^2 + (x_B - x_A)^2}}{z_B - z_A + h_A^B}\right)$$

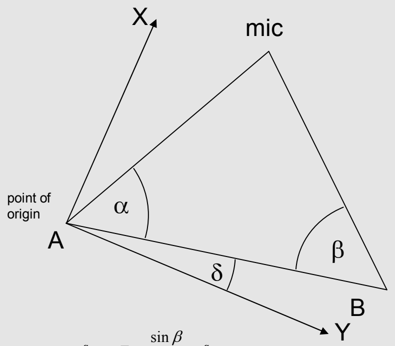
$$\vartheta_B^{A} + v_{2+4n+2} = \arctan\left(\frac{\sqrt{(y_A - y_B)^2 + (x_A - x_B)^2}}{z_A - z_B - h_A^B}\right)$$

$$s_A^B + v_{1+4n+4} = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2 + (z_B - z_A)^2}$$

$$s_B^A + v_{2+4n+4} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2}$$

$$s_{mic}^{mic_i} + v_{i+4n+6} = \sqrt{(x_{mic_i} - x_{mic})^2 + (y_{mic_i} - y_{mic})^2 + (z_{mic_i} - z_{mic})^2}$$

Determine the approximate values



$$s_{A-Mic} = \frac{\sin\beta}{\sin(\alpha+\beta)} s_{A-B}$$

$$X_{Mic} = \cos(100^{(g)} - (\alpha+\delta)) s_{A-Mic}$$

$$Y_{mic} = \sin(100^{(g)} - (\alpha+\delta)) s_{A-Mic}$$

$$Z_{Mic} = \frac{s_{A-Mic}}{\tan(z_A^{Mic})}$$

Results of the localization

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number of the star array	1	2	3	4	5
distance to the star array [m]	4.36	4.37	4.73	5.48	6.14
baseline length [m]	4.21	4.21	4.59	4.59	4.59
mean of absolute corrections of the horizontal angles [mgon]	0.4	0.3	0.5	0.5	0.7
mean of absolute corrections of the zenith angles [mgon]	0.6	0.3	0.6	0.5	0.6
mean of the mean point errors of the local coordinates [mm]	0.22	0.13	0.3	0.45	0.51
maximum mean error of the local coordinates [mm]	0.26	0.15	0.41	0.51	0.59
max NV	1.1	0.7	2.1	2.8	2.1
after the adjustment	0.4	0.2	0.6	0.7	0.8

Transformation into the target system

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Workflow:
1.centroid reduction for the microphone coordinates in both systems
2.Compute the translation parameter by the difference between the both centroids $T = \vec{x}_{cam\_centroid} - \vec{x}_{loc\_centroid}$
3.Estimate the rotation parameters
4.Transform the local coordinates into the target system
5.Calculate the residuals of the vendor given coordinates

rotation parameter
- quaternion rotation instead of the Euler rotation
- prevents us from calculating approximate values for the rotation parameters

$$R = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2q_1q_2 - 2q_0q_3 & 2q_1q_3 - 2q_0q_2 \\ 2q_1q_2 + 2q_0q_3 & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2q_2q_3 - 2q_0q_1 \\ 2q_1q_3 - 2q_0q_2 & 2q_2q_3 + 2q_0q_1 & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

Estimation of rotation parameters

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given:
- construct coordinates by the vendor (GfAI)
- localized coordinates

$$\begin{bmatrix} \Delta x \\ k \end{bmatrix} = \begin{bmatrix} A^T PA & B \\ B^T & 0 \end{bmatrix}^{-1} \begin{bmatrix} A^T P \Delta l \\ w \end{bmatrix}$$

$$b = q_0^2 + q_1^2 + q_2^2 + q_3^2 - 1$$

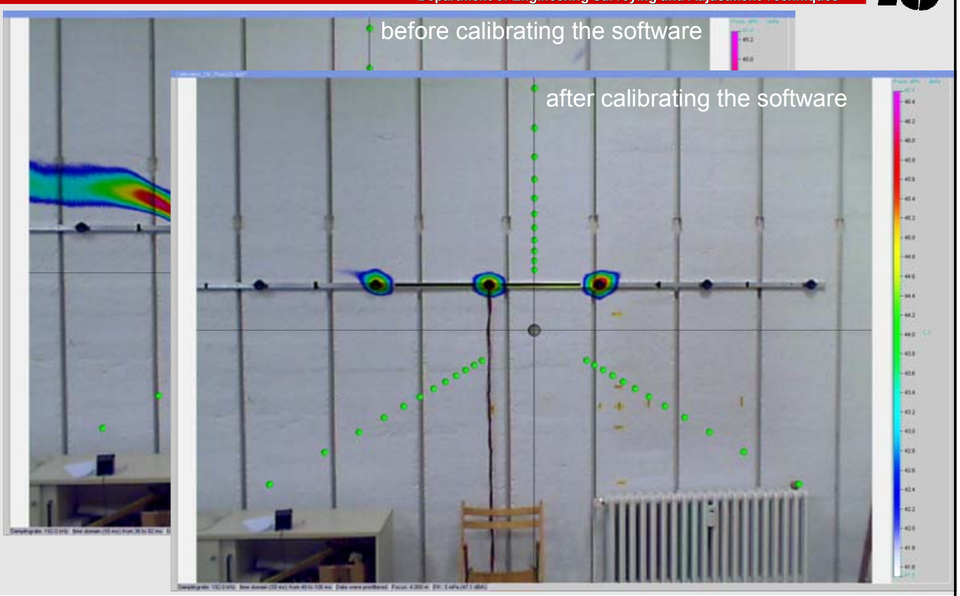
Parametric adjustment with one additional condition between the unknowns

Results:
- rotation parameters
- standard deviations of the parameters

Residuals to calibrate the acoustic software

Star	max ΔX [mm]	max ΔY [mm]	max ΔZ [mm]
1	4.8	-6.3	1.9
2	6.4	-13.0	11.4
3	-9.3	7.8	-2.6
4	9.0	7.7	-6.2
5	-8.1	4.4	-5.9

1. The residuals are significant (σ=±0.5mm).
2. Residuals show the diversity of the stars. Each star array slightly different.
3. Thus, a calibration is need for every new Acoustic Camera because the precision by constructing the device is to low.



… thank you. Are there any questions?

Christian Manthe
christian.manthe@tu-berlin.de

Since the **mechanical construction is a subject to inexactness** the as-built microphone positions must be calibrated.