Aalto University
School of Electrical
Engineering

Communication acoustics
Ch 17: Sound quality

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- Not only the sound quality of the end product, but during the development: the effect of different technical choices on sound quality
- How can we know the quality of products producing sound?
- Audio / HiFi
- Concert halls
- Noise annoyance
- Speech intelligibility / Public address
- Hearing aids / cochlear implants
- Razors / Car engine sounds / Mechanical products
- Musical instruments

Two meanings of term ’quality’

- Quantity vs Quality
  - Categorization by type or class of objects
  - When two observations or entities cannot be compared on the same (metric) scale they are said to be qualitatively different (is 1 meter more than 0.5 kilograms?)

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  - When two observations or entities cannot be compared on the same (metric) scale they are said to be qualitatively different (is 1 meter more than 0.5 kilograms?)
- Quality as synonym for ’excellence’
  - To grade or rank objects on a subjective scale of preferability such as good – poor
  - This book: ’excellent’ means good, desired, valuable etc

Sound quality and psychoacoustics

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- Basic results are of course very useful
- In sound quality the expectations, mood, and other cognitive factors are important
- Judged sound quality for devices or communication channels depends heavily on expectations
- Basic psychoacoustic experimentation techniques may not be used

Evaluation and measurement of sound quality

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- Subjective quality can be evaluated by listening experiments, for example:
  - Compare to "perfect quality" reference to find out if any degradation can be noticed
  - Compare two or more sounds and sort then by quality preference
  - Characterize sound quality by conceptual description (such as not annoying, slightly annoying, annoying, very annoying)
  - Give an overall quality rating on a numerical scale
  - Give a rating for a specific quality factor (numerical scale)
  - Give quality ratings for several different quality factors (multidimensional scaling)

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  - Give quality ratings for several different quality factors (multidimensional scaling)
- Based on subjective experimentation, a computational (objective) measure and model can be derived to simulate the perceived quality
  - Objective measures are less laborious and yield high repeatability
  - It is important to check the validity range of a model

Systemic framework for sound quality

Sounds of the problem domain => Subjective listening experiments => Data analysis (= quality ratings) => Sound quality models and theories

The development of sound-quality models and theories.

Sound source signal analysis => Signal and auditory features mapping to quality factors => sound quality measures

A general structure of a computational sound quality model

Subjective sound quality measurement

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- Principle: ask opinion of some aspect of sound quality in numerical scale with anchors, take an average + other statistical measures

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- Principle: ask opinion of some aspect of sound quality in numerical scale with anchors, take an average + other statistical measures
- Standardized methods to measure, e.g., (ITU-T P.800 (1996))

Value	Quality (MOS)	Impairment (DMOS)
5	Excellent	Imperceptible
4	Good	Perceptible, not annoying
3	Fair	Perceptible, slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Subjective sound quality measurement

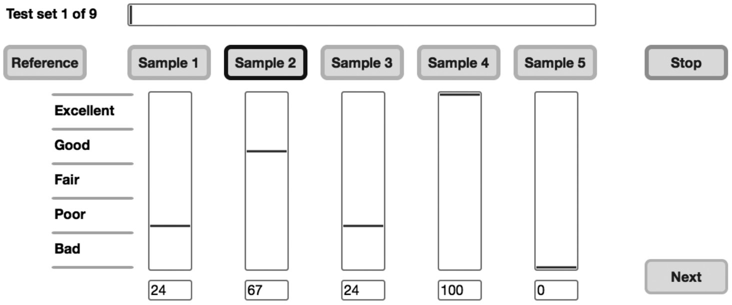
- MOS scales have been also defined for measurement of improvement or degradation of quality

Value	Categories (CMOS)
3	Much better
2	Better
1	Slightly better
0	About the same
-1	Slightly worse
-2	Worse
-3	Much worse

Subjective sound quality measurement

Multiple-stimulus hidden reference with anchors (MUSHRA)

- ITU-R BS.1534-1 (2003), ITU-R BS.1534-1 (2014)
- Originally: fast testing of audio codecs
- Reference (clean audio), test items, hidden reference, low-passed signals as anchors



Audio quality

- Audio content production
  - Product is finalized in mastering studio
  - Consumer should perceive the audio content in the same way as the audio engineering in the mastering studio

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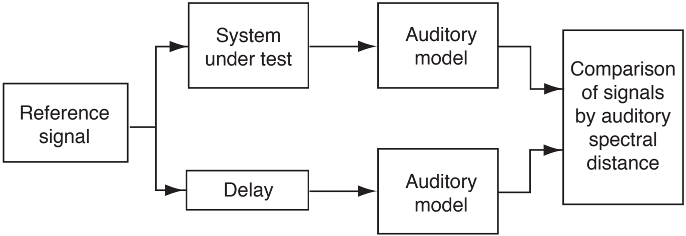
- Audio content production
  - Product is finalized in mastering studio
  - Consumer should perceive the audio content in the same way as the audio engineering in the mastering studio
- How to measure similarity?
- Typically the degradations in transmission channel are measured, not the differences in perceptions

Monaural audio quality

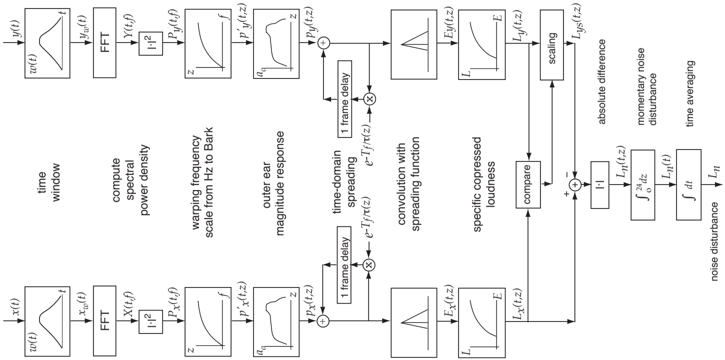
- Degradations of audio present by listening only one channel
- Deviations in:
    - Magnitude response
    - Phase and group delays
    - Non-linear distortions
    - Signal-to-noise ratio

Perceptual model for monaural audio quality

- Simple distance measures between original and reproduced audio do not tell much about perceptual difference
- Could we use auditory models to estimate perceived difference
- Principle:



Perceptual audio quality measure (PAQM)



Adapted from Beerends and Stemerdink (1992)

- Evolved to PEAQ (Perceptual audio quality) standardized measure
- Valid in limited applications

Spatial audio quality

- Tests with 5.1 surround: Spatial quality corresponds to 30% of total quality
- If sound is degraded by colorations, spatial quality looses its value
- How to measure spatial quality subjectively?
  - Comparison with reference, if exists and can be brought to listening room
  - Not simple solutions exist
- How to measure spatial quality objectively?
  - Binaural auditory models under research, standardization has failed

Quality of speech communication

- Speech intelligibility
- Speaker recognizability
- Speech naturalness
- Subjective and objective measurement

Speech quality: subjective measurement

- Articulation tests and articulation score
  - /CV/ or /CVC/ sequences used to measure recognition percentage
- Intelligibility test and intelligibility score
  - recognition percentage using meaningful words or sentences
- Rhyme tests (RT)
  - using "rhyme" words or syllables (in Finnish: /patti/, /tatti/, /katti/)
- Diagnostic rhyme tests (DRT)
  - modifying single distinctive feature at a time (nasality, voicing, etc.) in RT
- Speech interference tests (find a disturbing noise level of 50% articulation)
- Quality comparison method, including pairwise comparison methods
- Other methods
  - Indirect judgement tests (PARM, QUART)
  - Communicability tests (communicate a drawing task, measure the difficulty)
  - Task recall tests (memorizing ability)
  - Noise suppression tests

Speech quality: objective measurement

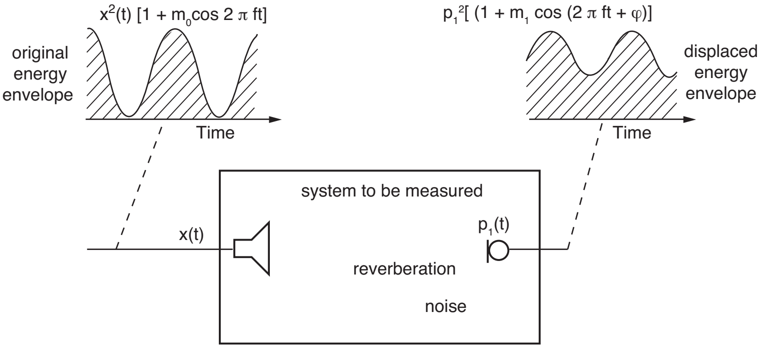
- Articulation index (AI)
  - for measuring a (linear) speech transmission channel with additive noise
  - articulation loss is assumed to be additive from 20 frequency bands
- Percentage articulation loss of consonants (%ALcons)
  - measure of speech intelligibitly, estimated from room acoustic parameters
- Room acoustical indices, see below
- Speech transmission index (STI, STIPA)
  - based on modulation transfer function, see below
- Signal-to-noise ratio (SNR)
  - ratio of speech vs. noise (power) level (in dB)
  - segmental SNR (SNRseg) based on short-time segmental SNRs
- Spectral distance measures
- Auditory sound quality measures (based on auditory modeling)
- Other methods
  - weighted spectral slope distance
  - LPC (linear prediction) distance measure

Modulation transfer function

- The auditory system analyzes signals by critical bands
- Each band is analyzed by signal level, i.e., modulation envelope
- More important than the exact transfer function is modulation transfer function, i.e., how signal modulations in each critical band are transmitted
- The auditory system is most sensitive to modulations of about 4 Hz
- Modulation transfer is degraded by:
  - Reverberation (lowpass of modulation)
  - Background noise (reduction of relative modulation)
  - These effects are multiplicative (cascaded)
- Modulation transfer function is a mathematically motivated approximation of auditorily relevant signal transfer analysis

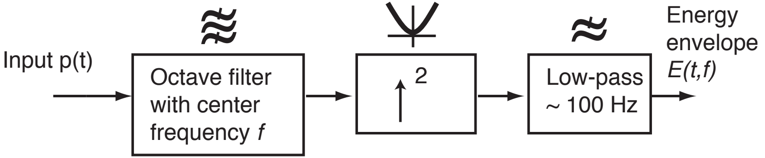
Effect of reverberation and noise on modulated sound

- Depth of modulation changes due to reverberation and noise



Link to commercial product demo

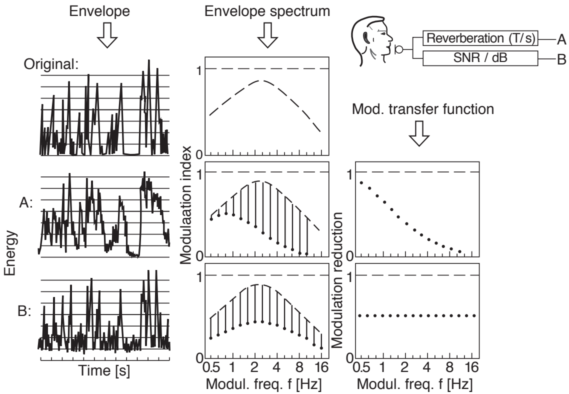
Measuring the envelope



- Similar to auditory modeling
- m_1 can be estimated:

$$m_1(f, f_{\mathrm{m}}) = 2\,\frac{\sqrt{\left|\int_t E_1(t,f)\sin(2\pi f_{\mathrm{m}} t)\,dt\right|^2 + \left|\int_t E_1(t,f)\cos(2\pi f_{\mathrm{m}} t)\,dt\right|^2}}{\int_t E_1(t,f)\,dt}$$

Effect of noise and reverberation on modulation transfer function



Adapted from Houtgast and Steeneken (1985)

Speech Transmission Index STI

- Measure *m* with many carrier frequencies and modulation frequencies, take logarithm-like-measure and take a weighted average (Eq. 17.8)
- Speech transmission index (STI) optimally reflects the intelligibility of speech over measured channel
- STI measurement requires presentation of all carrier-frequency-pairs at separate times – slow
- STIPA uses limited number of combinations (gray boxes), and presents at the same time

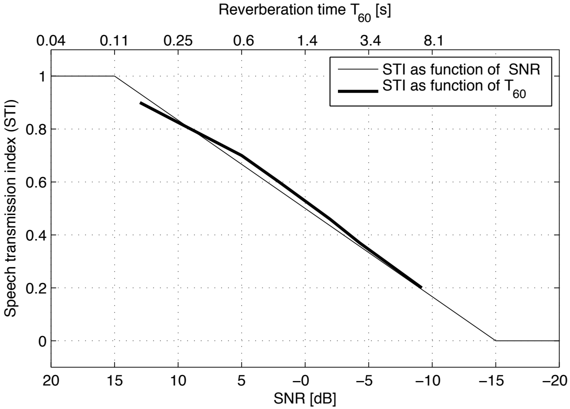
Carrier-frequency and modulation pairs

- STI: all boxes
- STIPA: gray boxes

Octave band

Modulation frequency	125	250	500	1k	2k	4k	8 kHz
F_1 = 0.63 Hz							
F_2 = 0.8 Hz							
F_3 = 1.0 Hz							
F_4 = 1.25 Hz							
F_5 = 1.6 Hz							
F_6 = 2.0 Hz							
F_7 = 2.5 Hz							
F_8 = 3.15 Hz							
F_9 = 4.0 Hz							
F_{10} = 5.0 Hz							
F_{11} = 6.3 Hz							
F_{12} = 8.0 Hz							
F_{13} = 10 Hz							
F_{14} = 12.5 Hz							

Dependence of STI on noise and reverberation time



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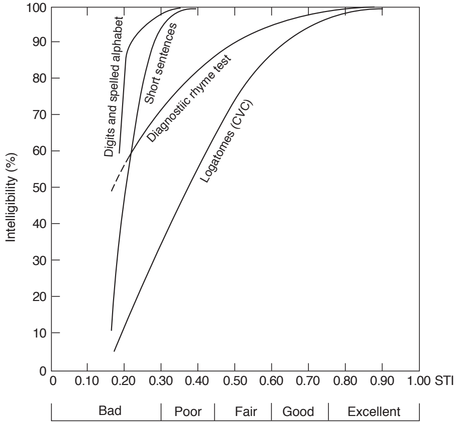
Correlation between STI and speech intelligibility



Adopted from (Houtgast and Steeneken, 1985 and Steeneken and Houtgast, 2002).

Objective speech quality measurement for telecommunication

- STI does not estimate e.g. naturalness of speech
- Mobile telecommunication codecs may make speaker unidentifiable, although intelligibility is good

Objective speech quality measurement for telecommunication

- STI does not estimate e.g. naturalness of speech
- Mobile telecommunication codecs may make speaker unidentifiable, although intelligibility is good
- More advanced methods needed
  - Models for general speech quality are expected to give a high MOS value only for natural-sounding and intelligible speech
  - Methods for measuring the perceptual effect of background noise suppression
  - Measures for echo suppression

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Objective speech quality measurement for telecommunication

- When a mobile device enters the market, sound quality is to be tested
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  - Effects of network problems delays, echos, background noise, background noise suppression
- Listening tests are not conducted, instead a standardized auditory-model-based evaluation tool is used
- 3GPP

Techniques for objective speech quality evaluation

- Perceptual speech quality measure (PSQM) 1998, withdrawn, e.g., temporal streching and compression of sound produced way too high error values
- Perceptual evaluation of speech quality (PESQ) 2002, tolerant to temporally varying jitter
- Telecommunications objective speech quality assessment (TOSQA) 2003, input through acoustic channel
- Perceptual objective listening quality assessment) POLQA 2011, also broad-band codecs
- Hearing-aid speech quality index (HASQI) 2014, sound-quality of hearing aids

The devices entering the markets have to produce enough high score with some of the mentioned techniques

Techniques for evaluation of the effect of background noise

- Mobile phones often involve algorithms to suppress background noise using non-linear DSP methods with time-variant processing
  - Non-linear noise-suppression algorithms try to reduce noise
  - How much does the algorithm reduce the problem
  - Does the algorithm introduce some new artifacts?

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- Standardized MOS scales for listening tests

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  - Non-linear noise-suppression algorithms try to reduce noise
  - How much does the algorithm reduce the problem
  - Does the algorithm introduce some new artifacts?
- Standardized MOS scales for listening tests
- Objective measurement 3QUEST needs recordings in standardized noise field with and without processing

Similar techniques exist also for measurement of the effect of echoes in two-way communication channel

Sound quality in auditoria and concert halls

- Concert halls have been built for music
- Music has been composed for concert halls
- Evolution of acoustics based on trial-and-error
- Certain type of music needs certain acoustics

Perceptual attributes of concert halls

Defined by Beranek by personal listening,

- Intimacy or presence / Reverberation or liveness / Spaciousness: Apparent source width(ASW) / Spaciousness: Listener envelopment (LEV) / Clarity / Warmth / Loudness / Acoustic glare / Brilliance / Balance / Blend / Ensemble / Immediacy of response / Texture / Freedom from echo / Dynamic range and background noise level / Extraneous effects on tonal quality / Uniformity of sound
- List is subject to debate and further studies

Objective measures of concert hall acoustics

- Measure few impulse responses in the hall
- Compute the values from the responses
- Subject to criticism, correspondence to actual perceptual quality is questionable

Subjective level of sound	Sound strength G in decibels
Perceived reverberance	Early decay time (EDT)
Perceived clarity of sound	Clarity C_{80} in decibels
Apparent source width (ASW)	Early lateral energy fraction, J_{LF}
Listener envelopment	Late lateral sound level, L_J in decibels

Objective measures of concert hall acoustics

Examples of the measures

- Strength

$$G = 10\ \log_{10} \frac{\int_0^\infty p^2(t)\, dt}{\int_0^\infty p_A^2(t)\, dt}$$

- Clarity (energy ratio between the early and late response)

$$C_{80} = 10\ \log_{10} \frac{\int_0^{80\text{ ms}} p^2(t)\, dt}{\int_{80\text{ ms}}^\infty p^2(t)\, dt}.$$

- Lateral fraction (reflects the ratio of lateral sound in the overall response)

$$J_{\mathrm{LF}} = \frac{\int_{5\text{ ms}}^{80\text{ ms}} p_8^2(t)\, dt}{\int_0^{80\text{ ms}} p^2(t)\, dt}$$

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- Annoyance: general concept of noise quality, also, how noise may upset an operation or activity
- Disturbance is connected to negative feelings where the functioning of the subject is not necessarily disrupted
- Annoyance depends on signal and on context
  - Speech and laughter are disturbing in open-plan office, ventilation humming is ok
  - Speech intelligibility over distance is not desired in open-plan office, just opposite to theatres and auditoria
- Objective model for noise annoyance or disturbance explain only certain cases

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- Mechanic devices communicate their functioning to to the user
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- Examples:
  - Cars and work machines
  - Home appliances
  - Office equipment
  - Personal devices

References

These slides follow corresponding chapter in: Pulkki, V. and Karjalainen, M. Communication Acoustics: An Introduction to Speech, Audio and Psychoacoustics. John Wiley & Sons, 2015, *where also a more complete list of references can be found.*

References used in figures:

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