EarHealth: An Earphone-based Acoustic Otoscope for Detection of Multiple Ear Diseases in Daily Life

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Summary

Diagnosis

Related work

The idea

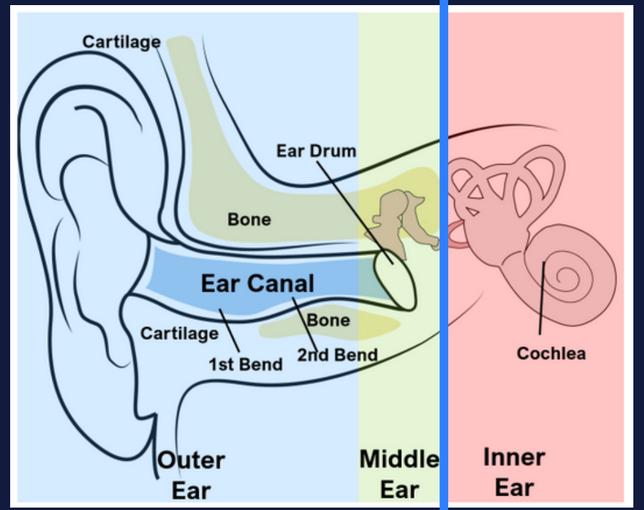
Implementation

Experiment

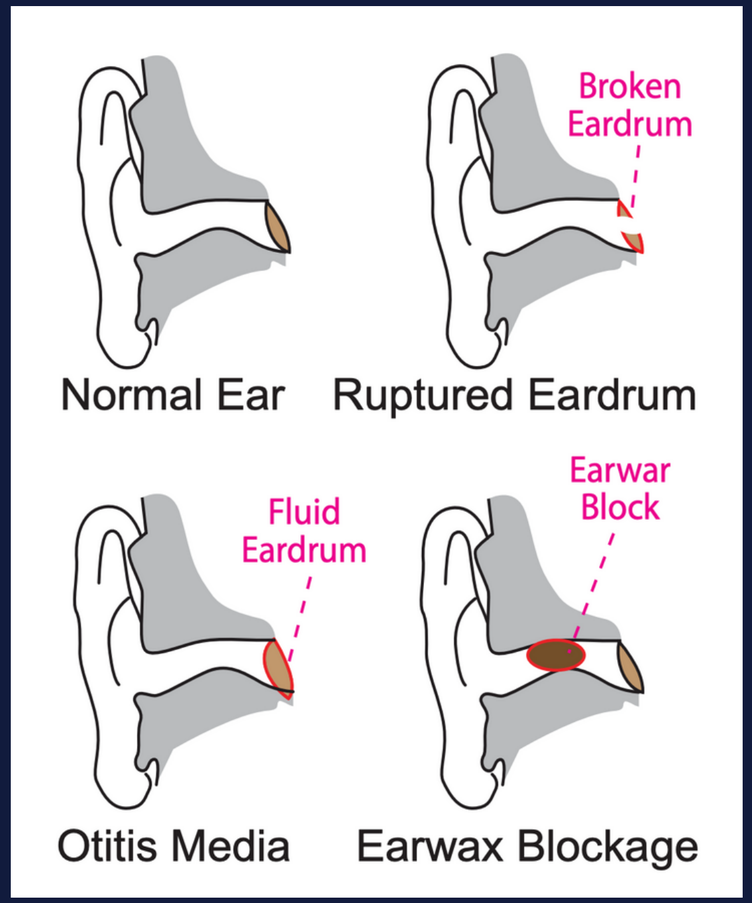
Evaluation

Diagnosis

The ear



Type of diseases



Possible causes

Exposure to loud noises

Aging

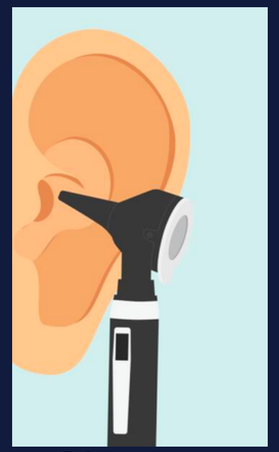
Headphones

! Monitor ear condition frequently !

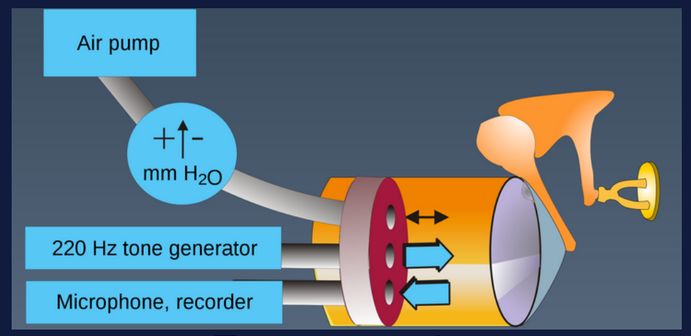
Related work

Existing ear monitoring solutions

Clinical solutions



Otoscopy



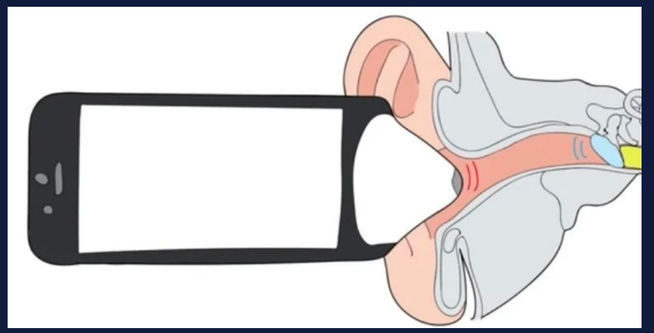
Tympanometry

- Expensive
- Painful
- Unconvinient

At home solutions

Acoustic reflectometers:

EarCheck Pro



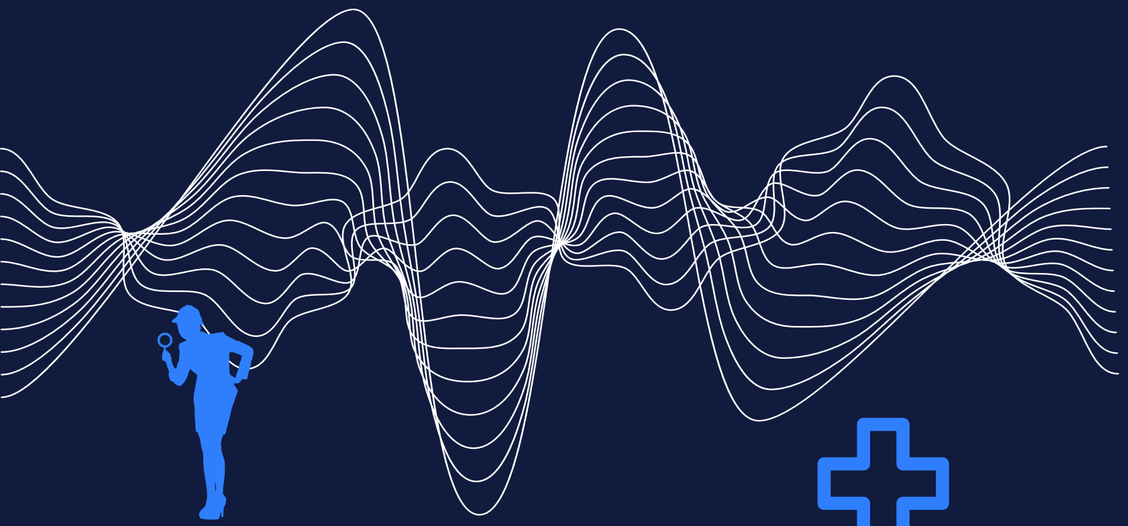
With smartphone

- Middle ear fluid only
- Constant threshold -> low generalization
- Not continuous monitoring devices

Related work

General research context

Ubiquitous acoustic sensing



behavior recognition

security

medical diagnosis

health monitoring

In-ear sensing

navigation

dietary monitoring

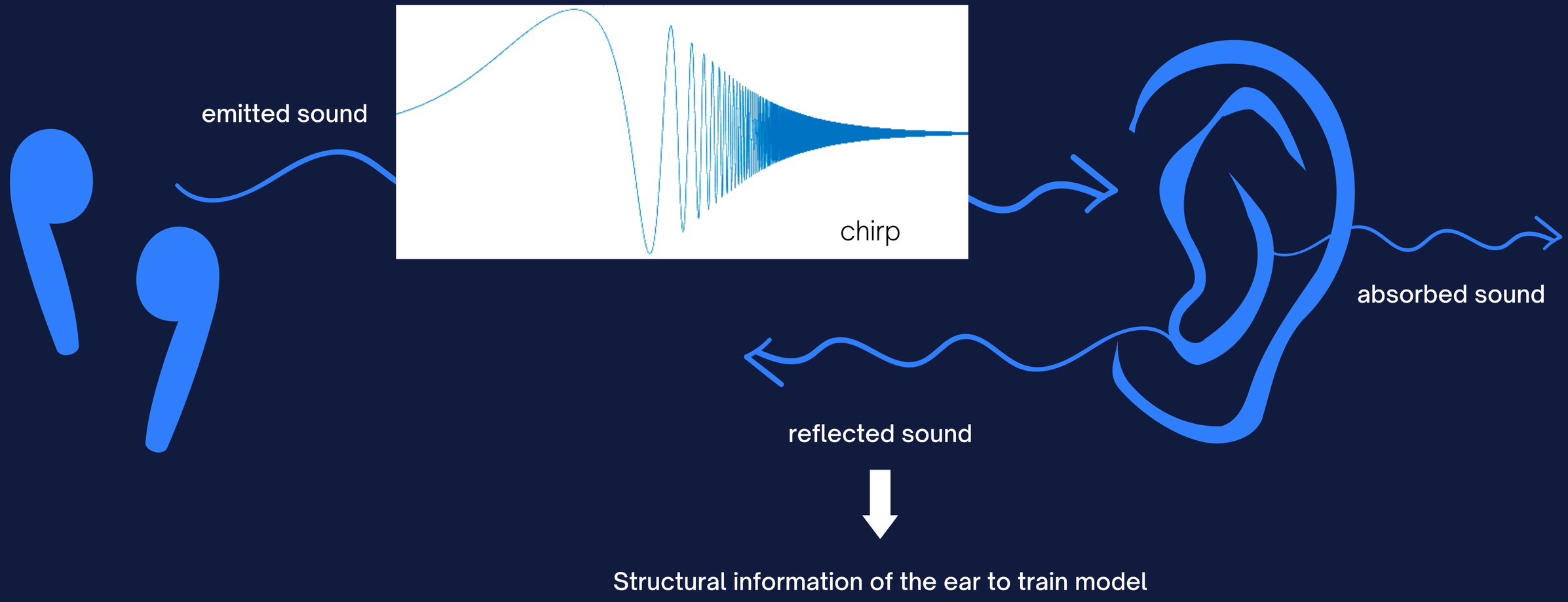
blood pressure

facial gesture detection

authentification

heart rate

The idea


emitted sound
chirp
absorbed sound
reflected sound
Structural information of the ear to train model

The idea

high eardrum mobility -> resonates well at multiple frequencies

inflammation + fluid behind the eardrum

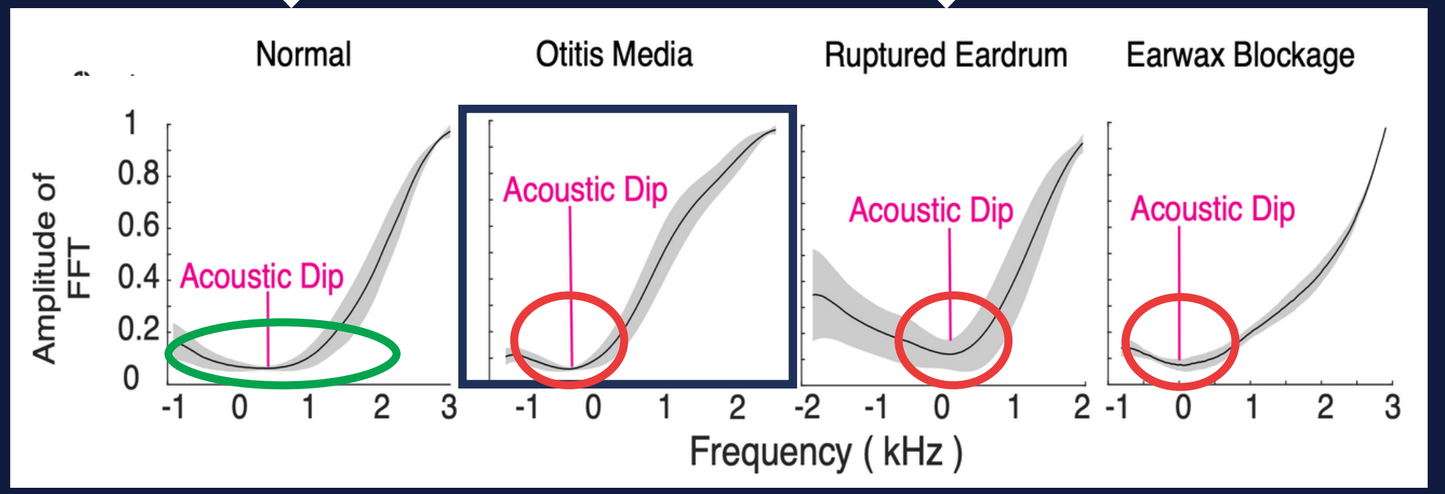
negative pressure + purulent effusion + middle earcavity

solid obstacles in the ear canal

Eardrum mobility

stiff -> reflexion

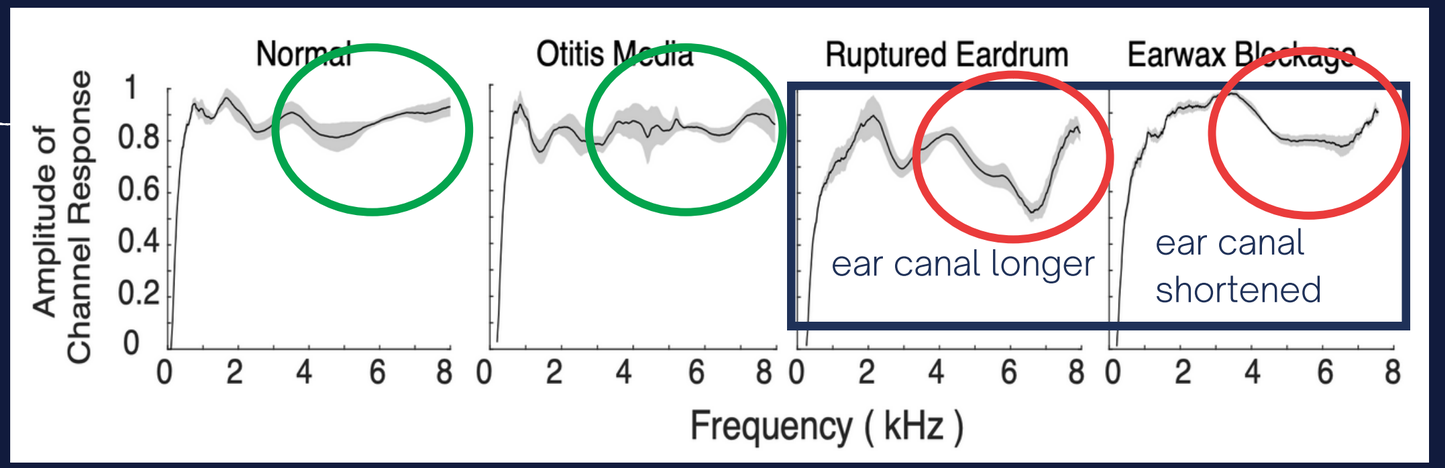
mobile -> propagation



c = r/i

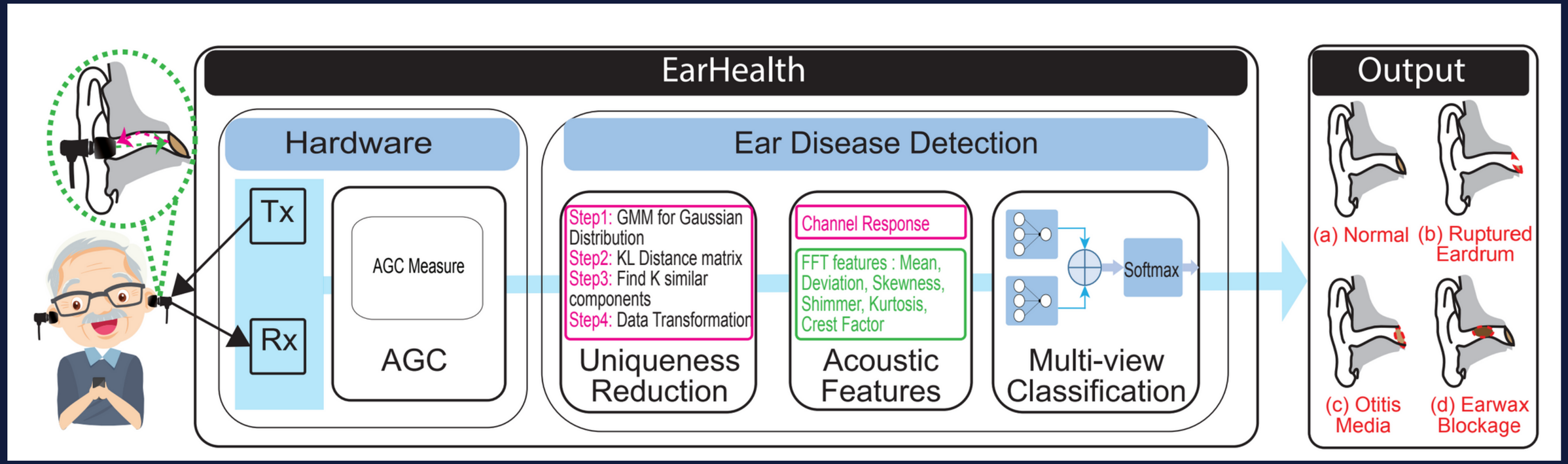
Canal structure (length)

different resonance frequencies



Implementation

Overview



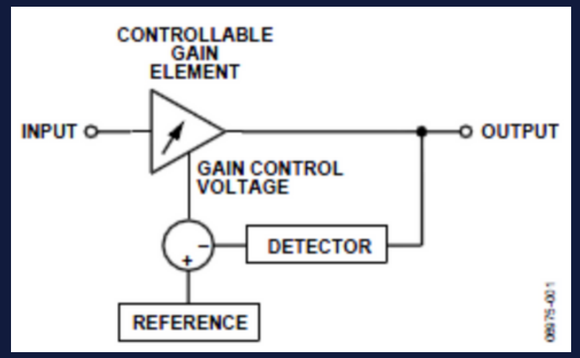
Implementation

Hardware - Automatic Gain Control

Problem:

Frequency selective speakers -> different frequencies for same audio stimulis

Different volume levels -> different amplifications



Solution:

Automatic Gain Control

1. measure frequency and volume response
2. compensate audio file using feedback
3. estimate output sound of the speaker

Implementation

Uniqueness Reduction

Problem:

Diversity of ear canal structures

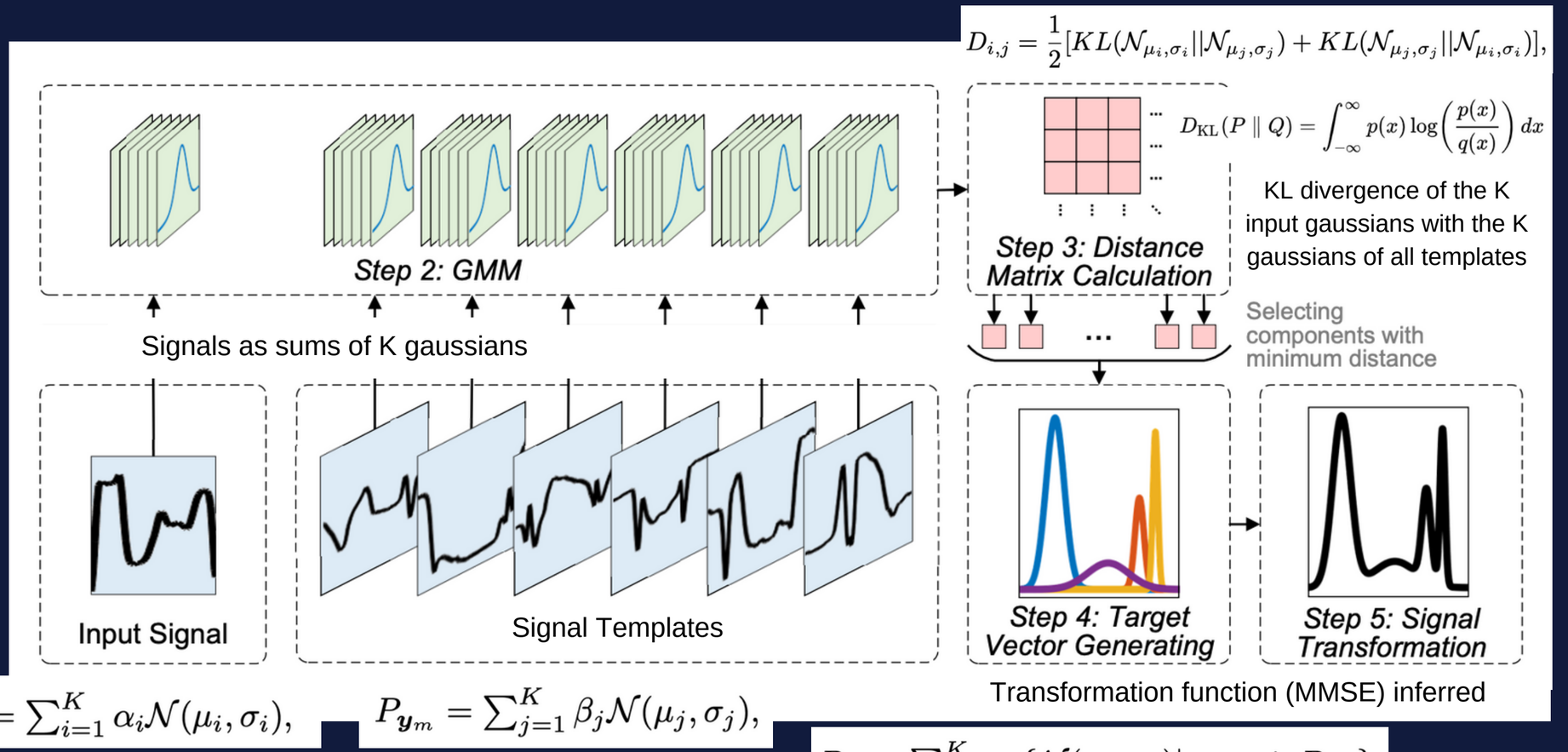
-> different reflexions

Solution:

Data transformation

(user signals into ear condition templates)

-> reduces impact of ear canal shape diversity



$$D_{i,j} = \frac{1}{2}[KL(\mathcal{N}_{\mu_i,\sigma_i}||\mathcal{N}_{\mu_j,\sigma_j}) + KL(\mathcal{N}_{\mu_j,\sigma_j}||\mathcal{N}_{\mu_i,\sigma_i})],$$

$$D_{\mathrm{KL}}(P \parallel Q) = \int_{-\infty}^{\infty} p(x) \log\left(\frac{p(x)}{q(x)}\right) dx$$

$$P_{\boldsymbol{x}} = \sum_{i=1}^{K} \alpha_i \mathcal{N}(\mu_i, \sigma_i),$$

$$P_{\boldsymbol{y}_m} = \sum_{j=1}^{K} \beta_j \mathcal{N}(\mu_j, \sigma_j),$$

$$P_{\boldsymbol{y}'} = \sum_{i=1}^{K} \gamma_i \{\mathcal{N}(\mu_j, \sigma_j) | arg\,min D_{i,j}\}.$$

$$\mathcal{F}(\boldsymbol{x}) = E(\boldsymbol{y}'|\boldsymbol{x}) = \int \boldsymbol{y}' \frac{P(\boldsymbol{x}, \boldsymbol{y}')}{P_x(\boldsymbol{x})} d\boldsymbol{y}',$$

Implementation

Acoustic features selection

Problem:

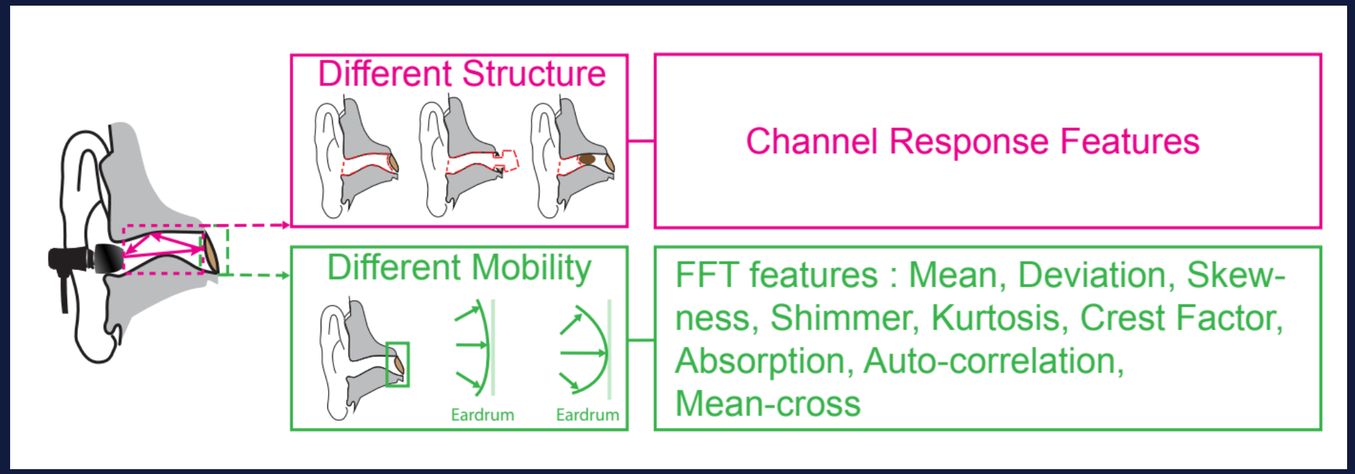
Minimum set of useful features

Solution:

Boruta iterative algorithm

- features against randomness (Benjamini Hochberg FDR)
- decision based on the iteration and relative uncertainty (Bonferroni)

Features selected



Implementation

Multi-view classifier

Problem:

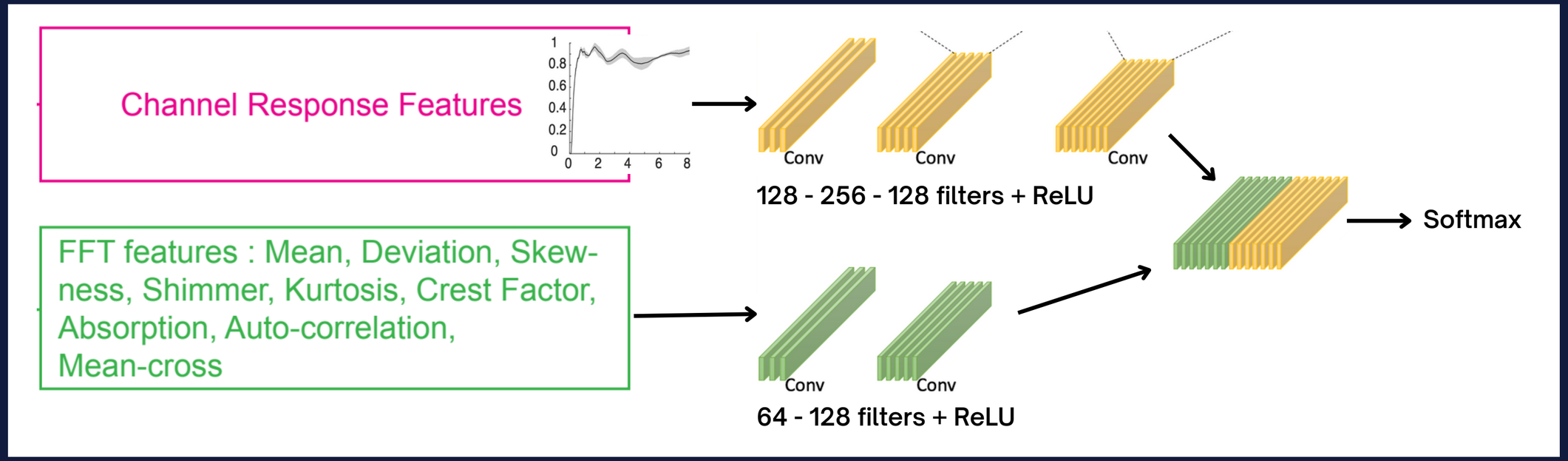
2 dimensions of features not highly dependent

-> hard to feed to a single neural network

Solution:

Ensemble Classifier

- backpropagation -> weight error correction
- activation functions -> non-linearities
- multi-layer -> low and high level features



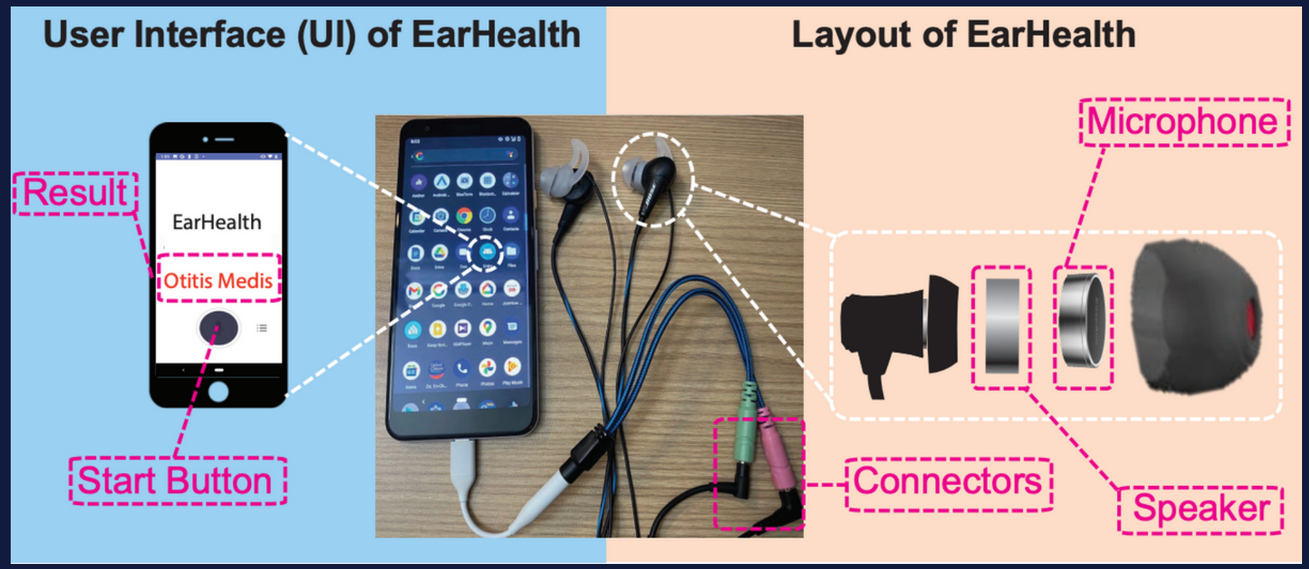
Experiment

Data of 92 subjects

- 27 normal ear condition
- 22 ruptured eardrum
- 25 otitis media
- 18 earwax blocage

Ground truth evaluated by clinical diagnosis

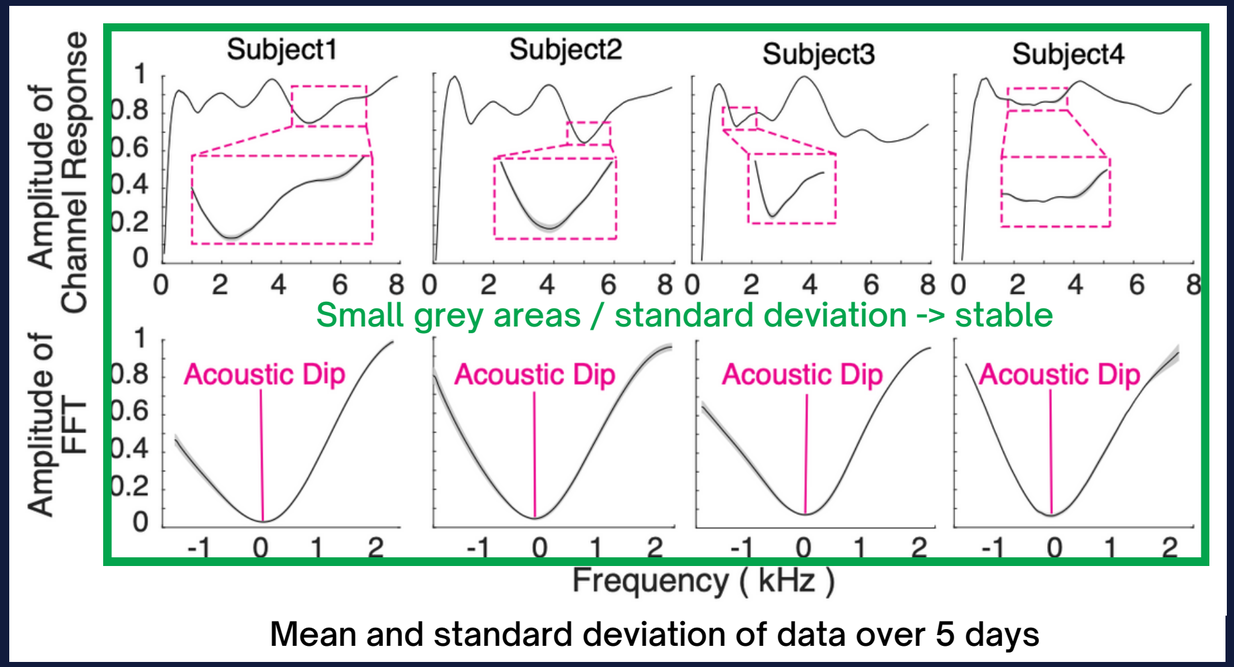
Sound stimuli = train of chirp (1s chirps
20 times without interval)



Evaluation

Checking for undesired behaviors

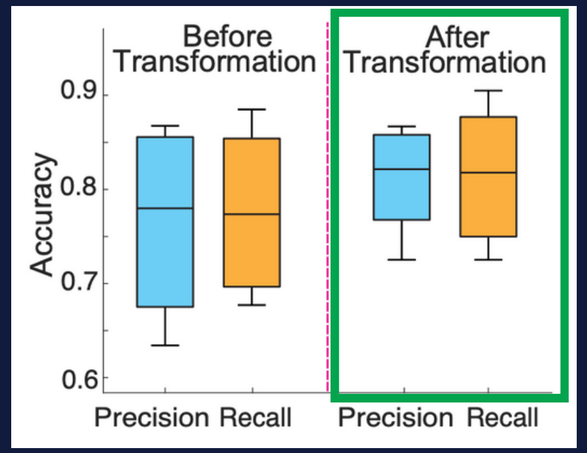
System stability and reliability



Mean and standard deviation of data over 5 days

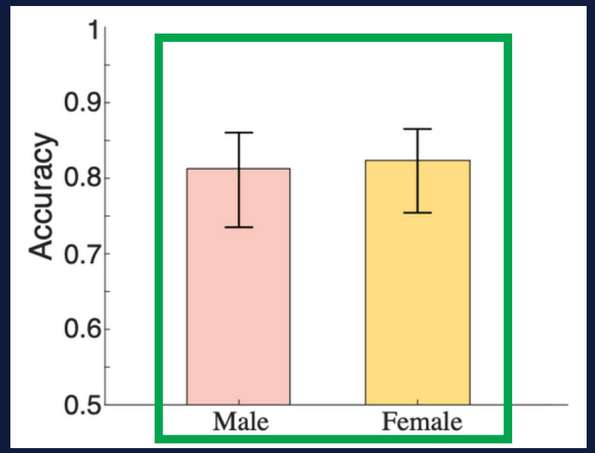
Ear canal uniqueness

Usefulness of data transformation



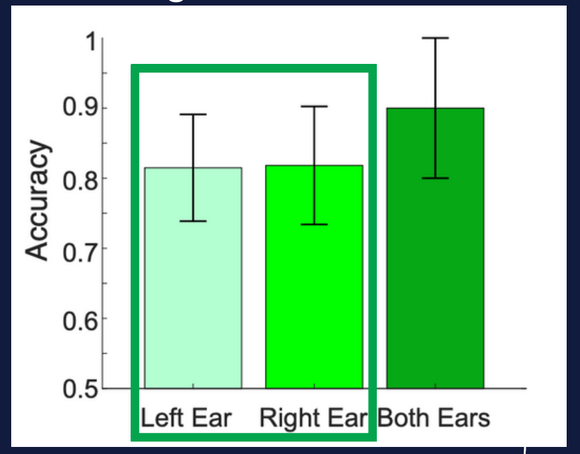
Gender

No influence



Left/right ear

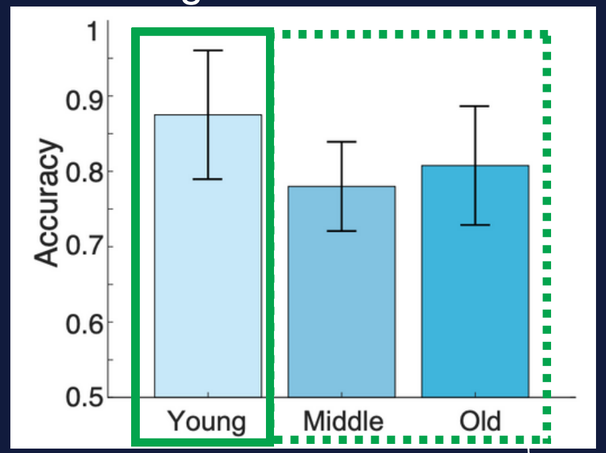
Unsignificant influence



data x2
-> more significant patterns

Age

Unsignificant influence



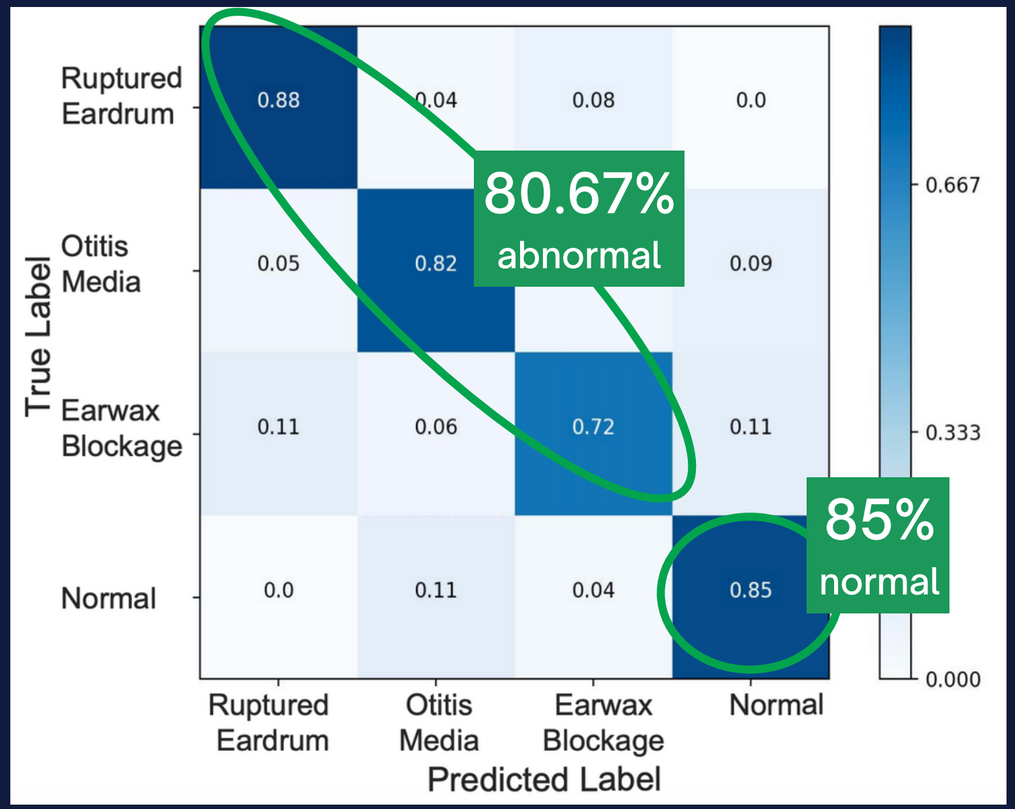
young
-> normal ear conditions

Evaluation

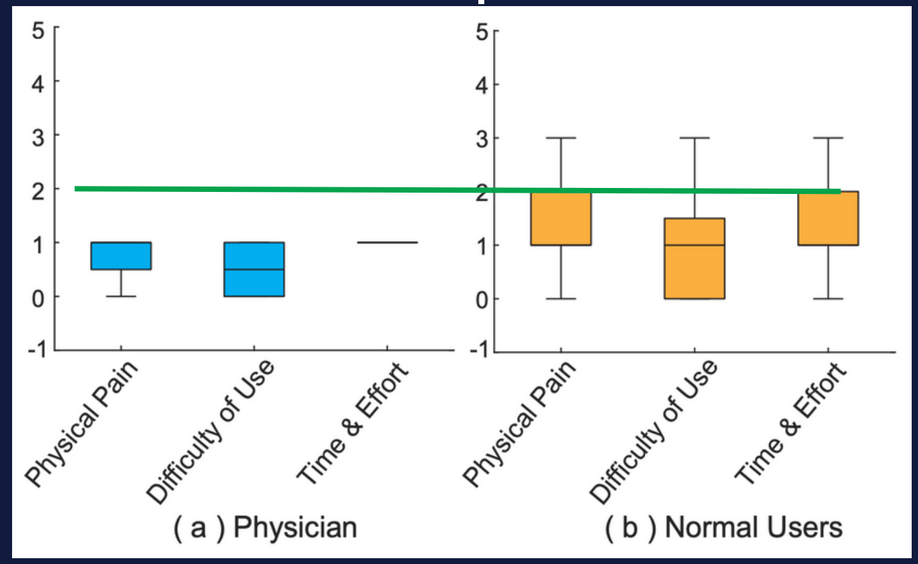
Overall performance and usability

Leave-one-out cross validation

Accuracy **82.6%**
overall



User experience



Resource efficiency

Smartphone platforms	Execution Time (ms)	Memory Usage (MB)	Average CPU Utilization (%)
Google Pixel 3A	343	29	43%
Google Pixel 3XL	220	36	30%
Google Pixel 4A	157	24	36%

Comparison with other solutions

System	Abnormal Conditions	Cost	Portable	Ease of Use	Performance
Pneumatic otoscopy	N/A	High	No	No	High
EarCheck Pro [8, 26]	One	Medium	No	Yes	77.6%
Smartphone-based [14]	One	Low	Yes	No	89%
EarHealth (Ours)	Three	Low	Yes	Yes	82.6%

Recap

Diagnosis

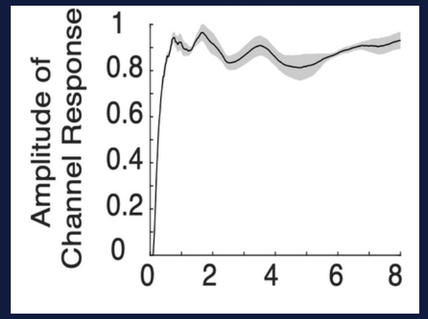
Related work

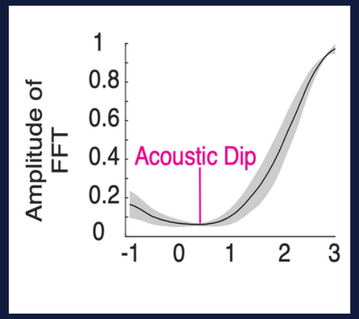
The idea

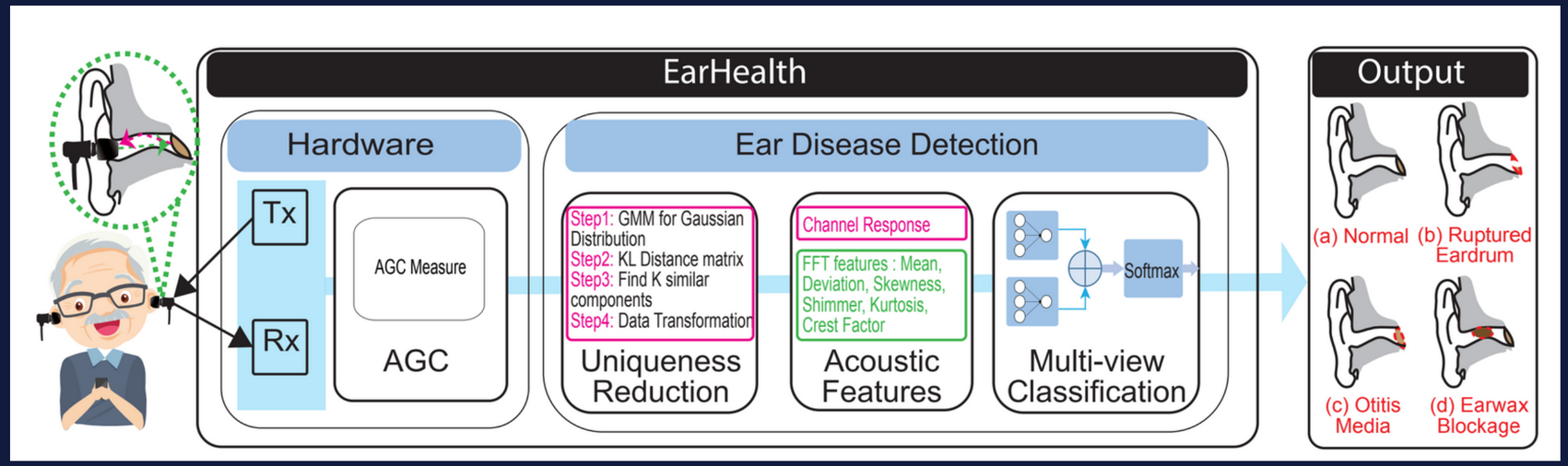
Implementation

Experiment

Evaluation







- Influences: age neglictable, gender X, left or right ear X
- System stable and reliable
- Influence of ear canal diversity among subject reduced thanks to data transformation
- 82.6% accuracy

Future work

Large scale evaluation

Personnalize earphone tip

Check for other factors' influence

Hairs, past surgeries, etc

Daily wearability for long-time ear monitoring