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

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Presentation overview

Diagnosis

Related work

The idea

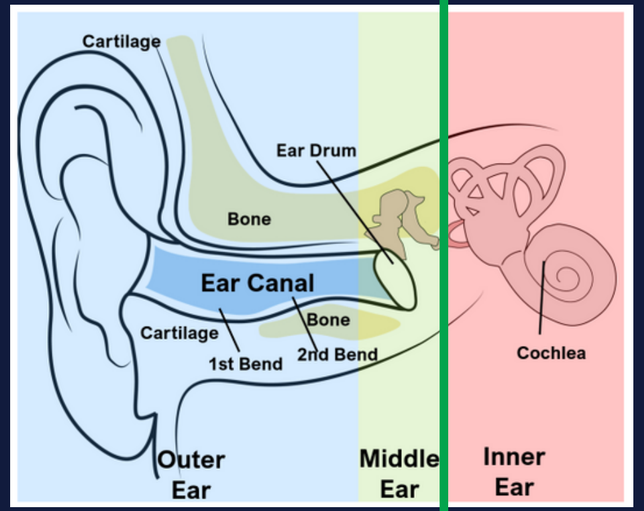
Implementation

Experiment

Evaluation

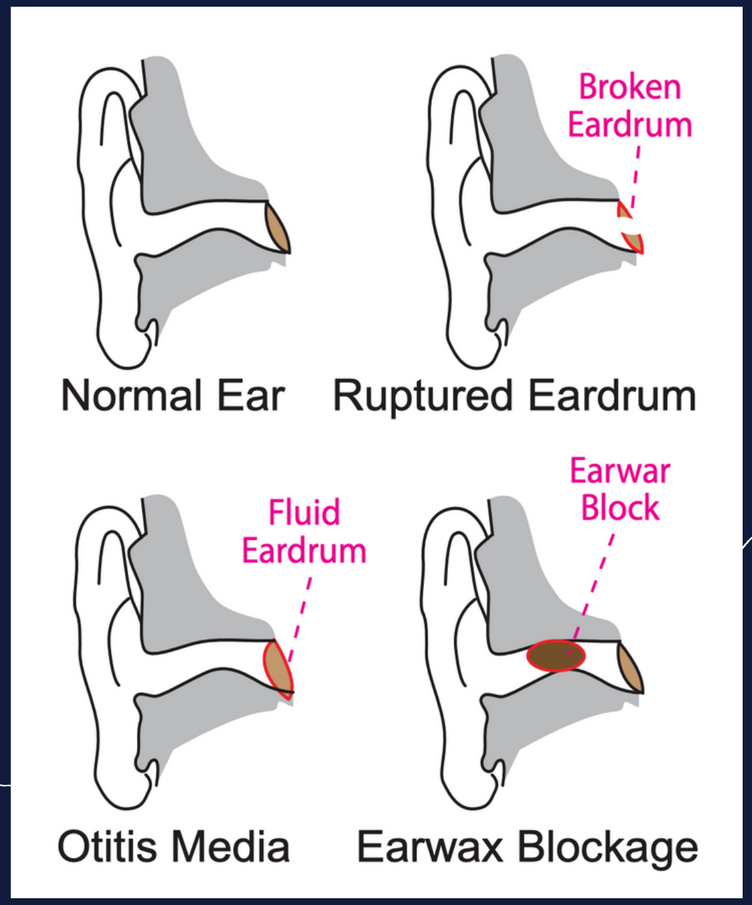
Diagnosis

The ear



(no showing signs in early stage ie before acute otitis media)

Type of diseases



(no showing signs)

Possible causes

Exposure to loud noises

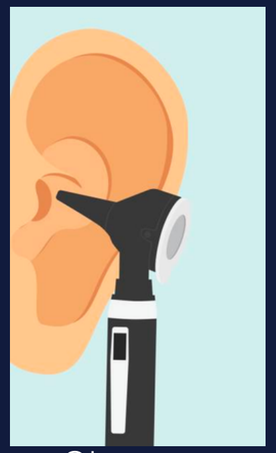
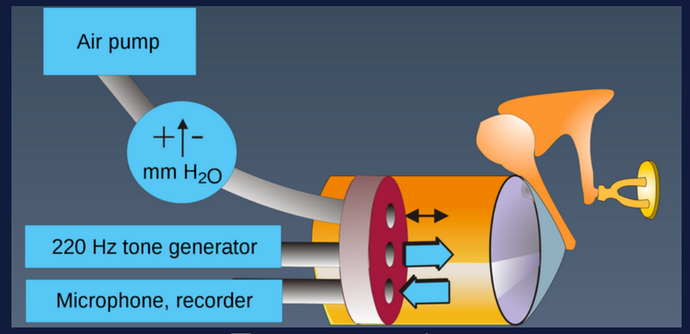
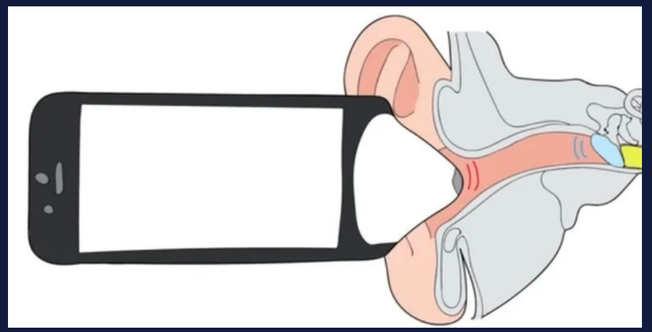
Aging

Headphones

! Need to monitor ear condition frequently !

Related work

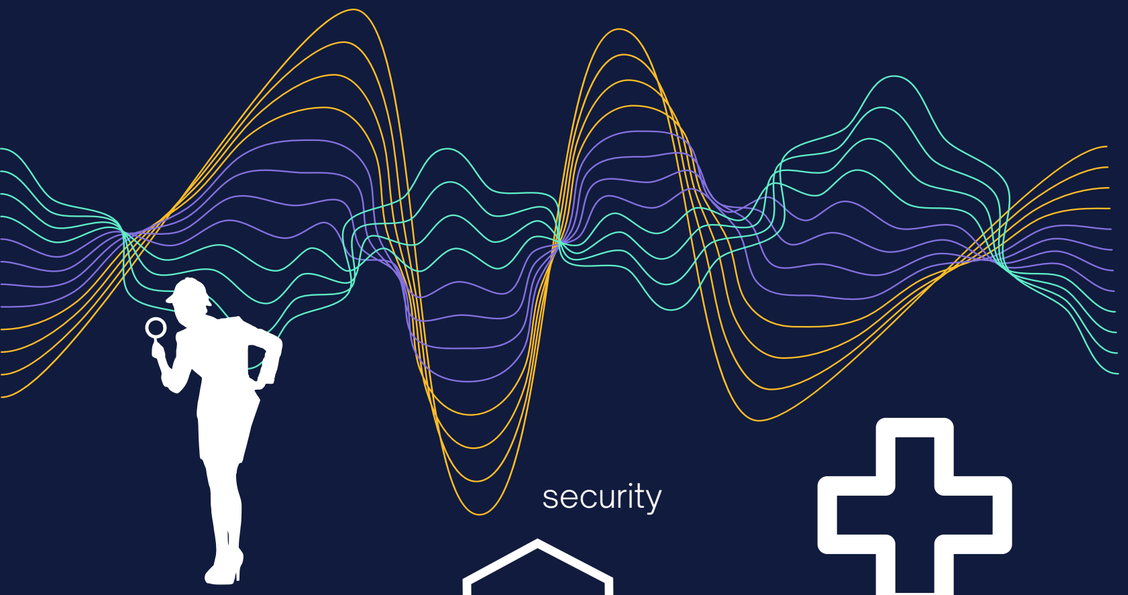
Existing ear monitoring solutions

Solutions	Clinical solutions	At home solutions
	 Otoscopy	 Tympanometry
		 EarCheck Pro
		 With smartphone
		Acoustic reflectometer for middle ear fluid
Limitations		
	Expensive Painful Unconvinient	Middle ear fluid diseases only Based on constant threshold -> low generalization Not continuous monitoring devices

Related work

General research context

Ubiquitous acoustic sensing



behavior recognition

security

medical diagnosis

health monitoring

navigation

blood pressure

In-ear sensing

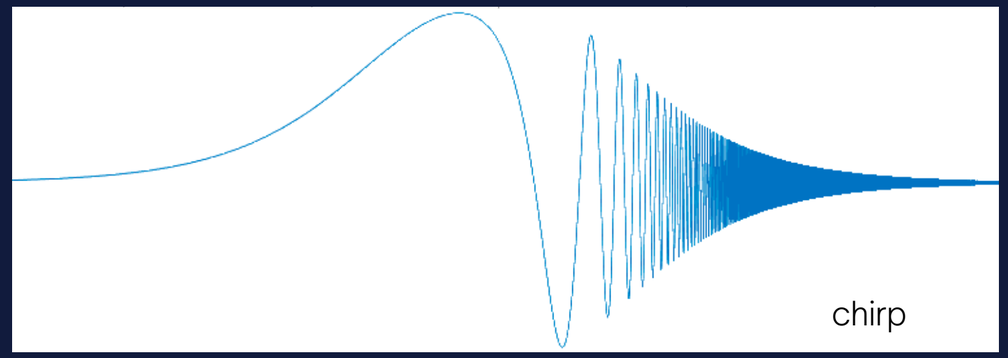
authentification

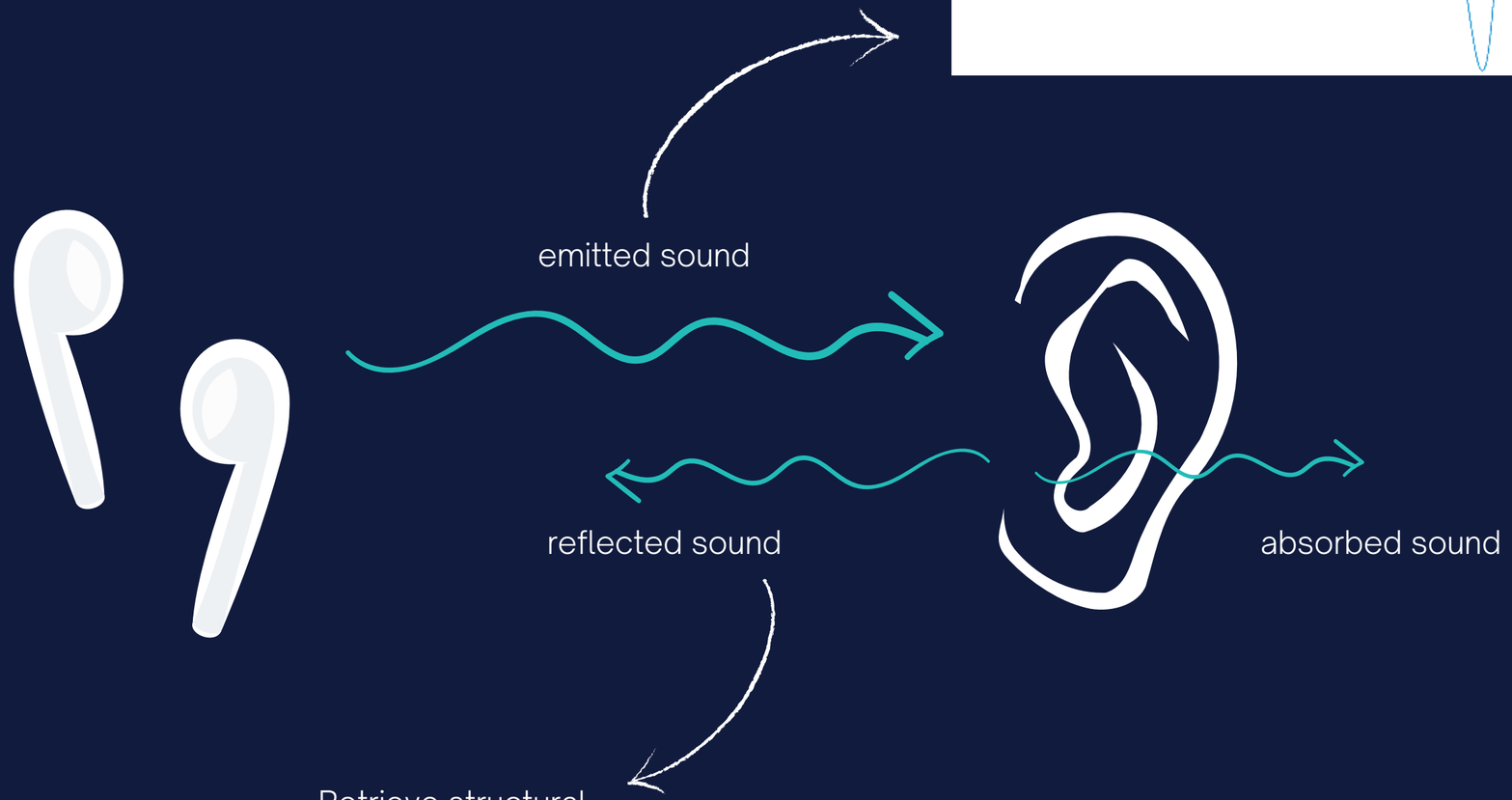
facial gesture detection

heart rate

dietary monitoring

The idea


chirp


emitted sound
reflected sound
absorbed sound
Retrieve structural information of the ear to train model

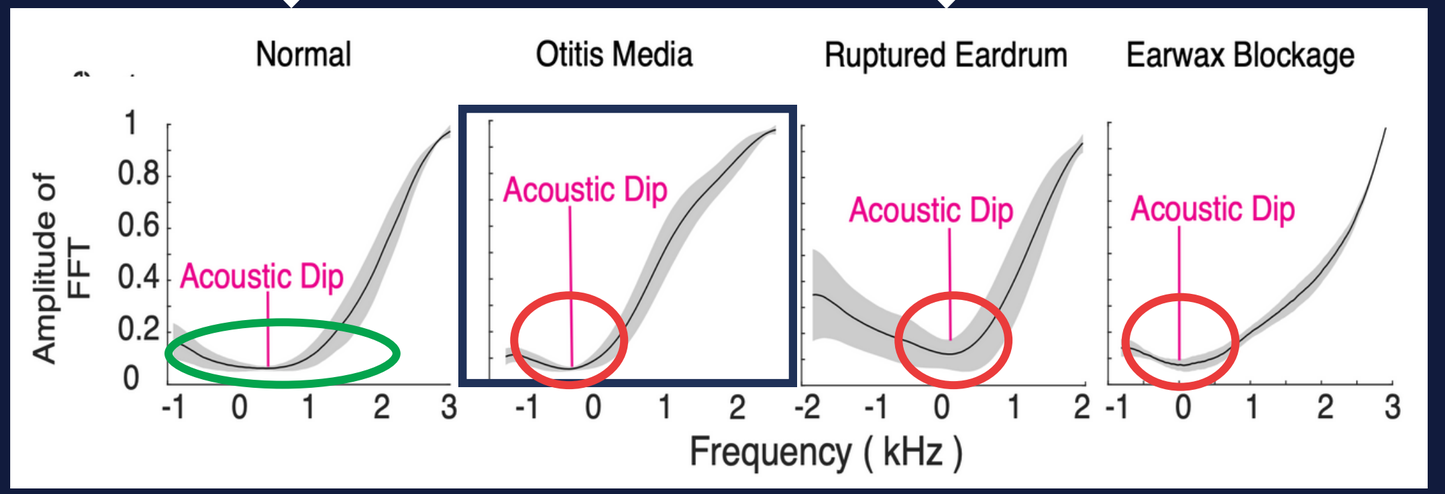
The idea

high eardrum mobility
-> resonates well at
multiple frequencies

inflammation
+ fluid behind
the eardrum

negative pressure
+ purulent effusion
+ middle earcavity

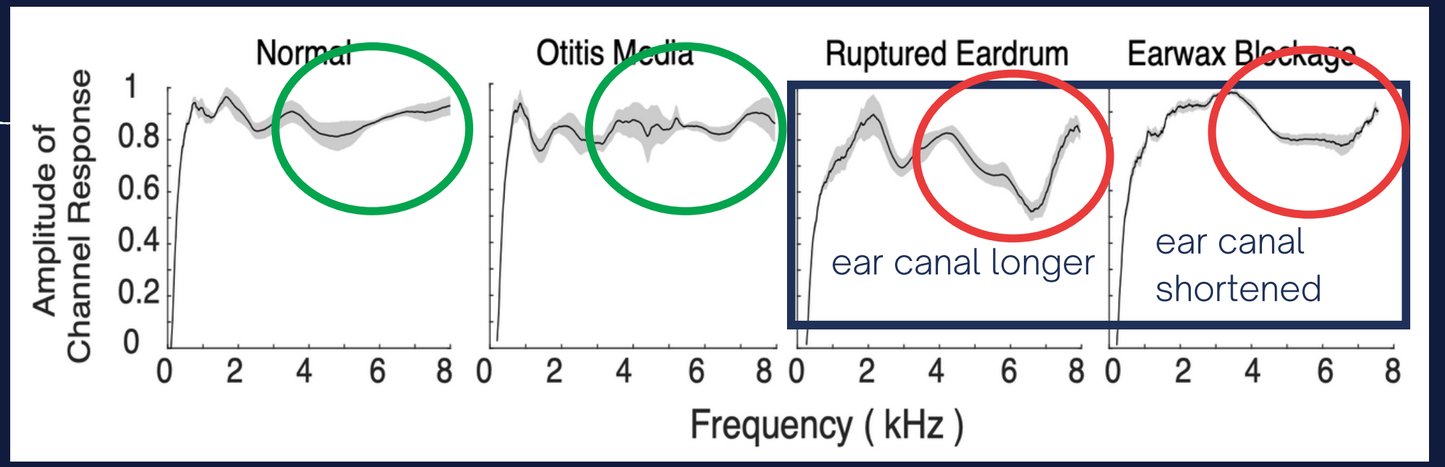
solid obstacles
in the ear canal



Eardrum mobility

stiff -> reflexion
mobile -> propagation

c = r/i

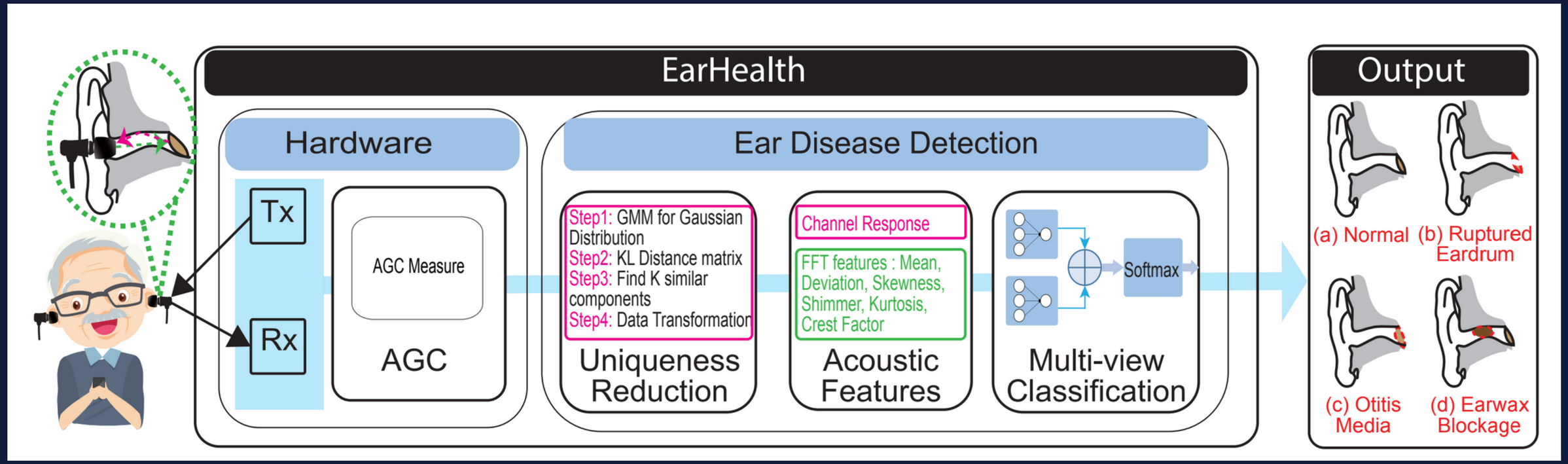


Canal structure (length)

different resonance frequencies

Implementation

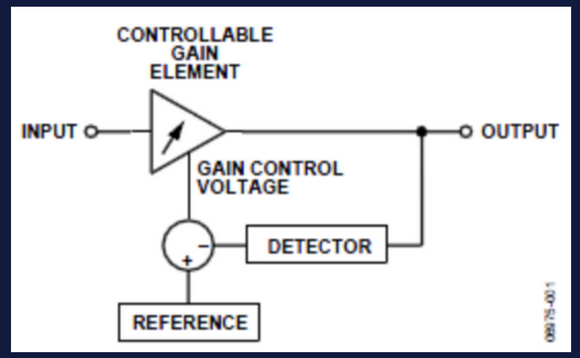
Overview



Implementation

Hardware - Automatic Gain Control

Problem:
Frequency selective speakers, ie different frequencies for same audio stimulis
Different volume levels -> different amplifications



Solution:
Automatic Gain Control

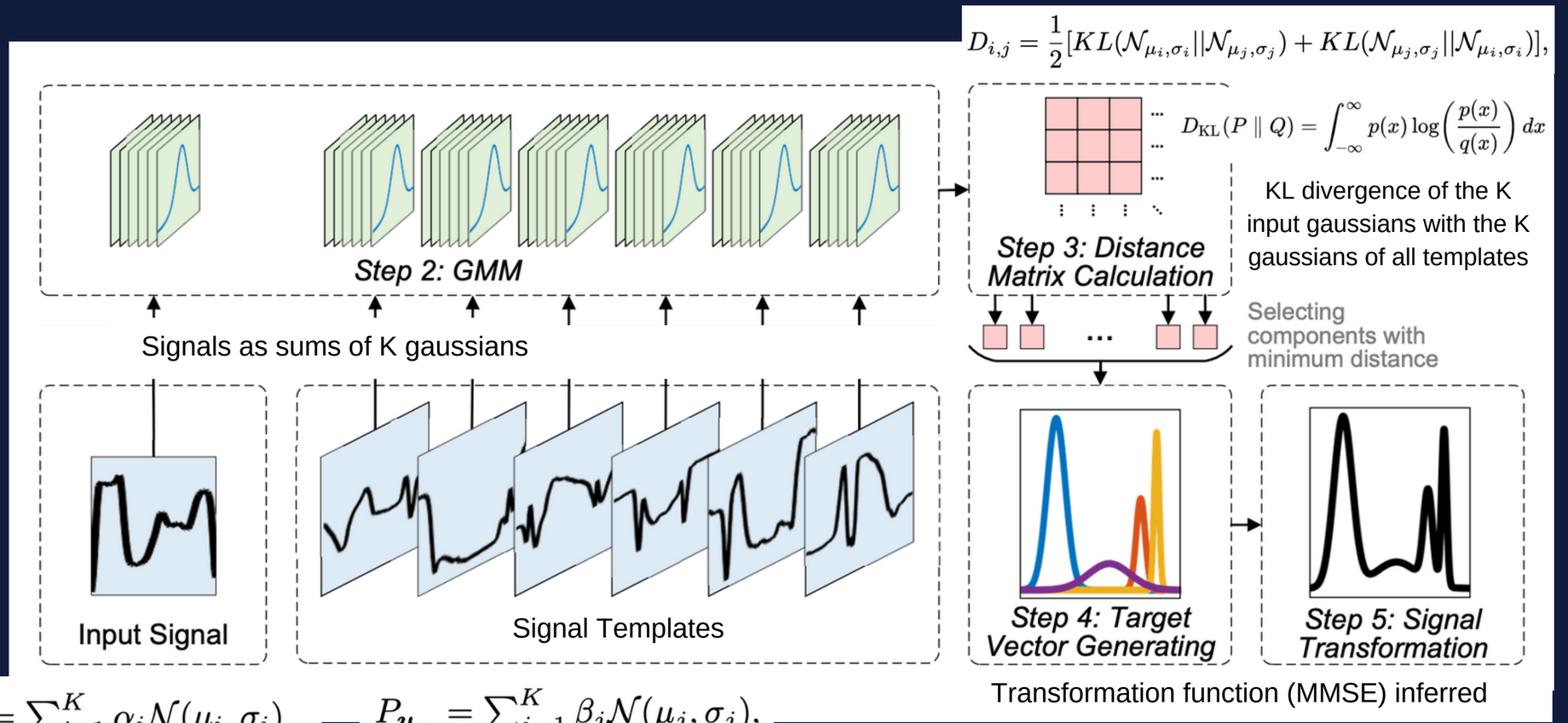
1. measure frequency and volume response of a chirp signal
2. compensate audio file using feedback
3. estimate output sound of the speaker

Implementation

Uniqueness Reduction

Problem:
Diversity of ear canal structures
-> different reflexions

Solution:
Data transformation technique (transform users' signals based on representative signals of all ear conditions)
-> reduces the impacts of ear canal shape diversity and sensor position differences



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

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

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

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

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

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

Implementation

Acoustic features selection

Problem:
Find minimum set of useful features

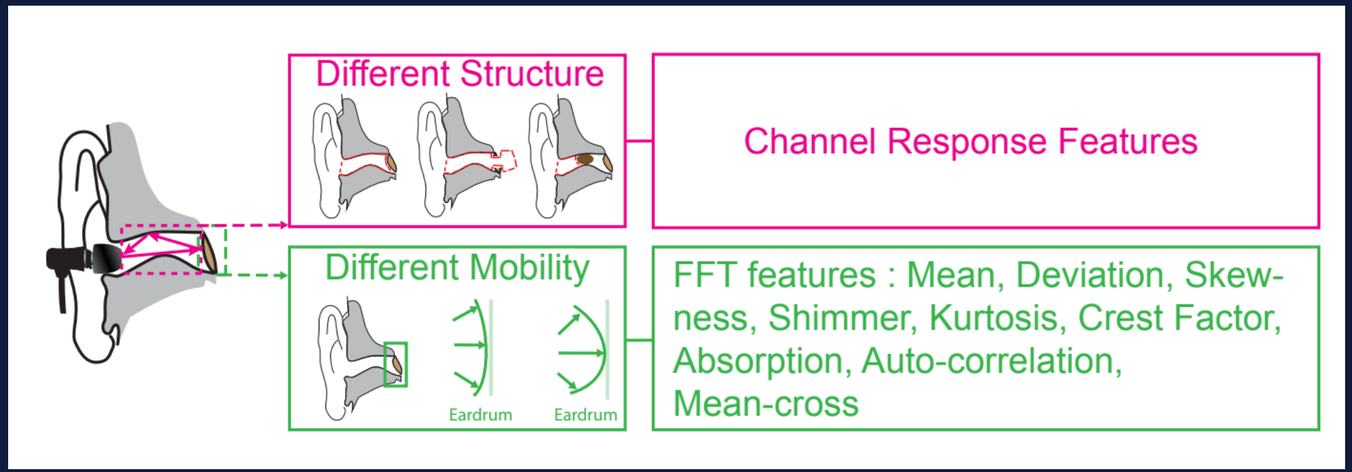
Solution:
Boruta iterative algorithm

- evaluate features against randomness
- make a decision for every feature based on the iteration and relative uncertainty

Benjamini Hochberg FDR

Bonferroni

Features selected:

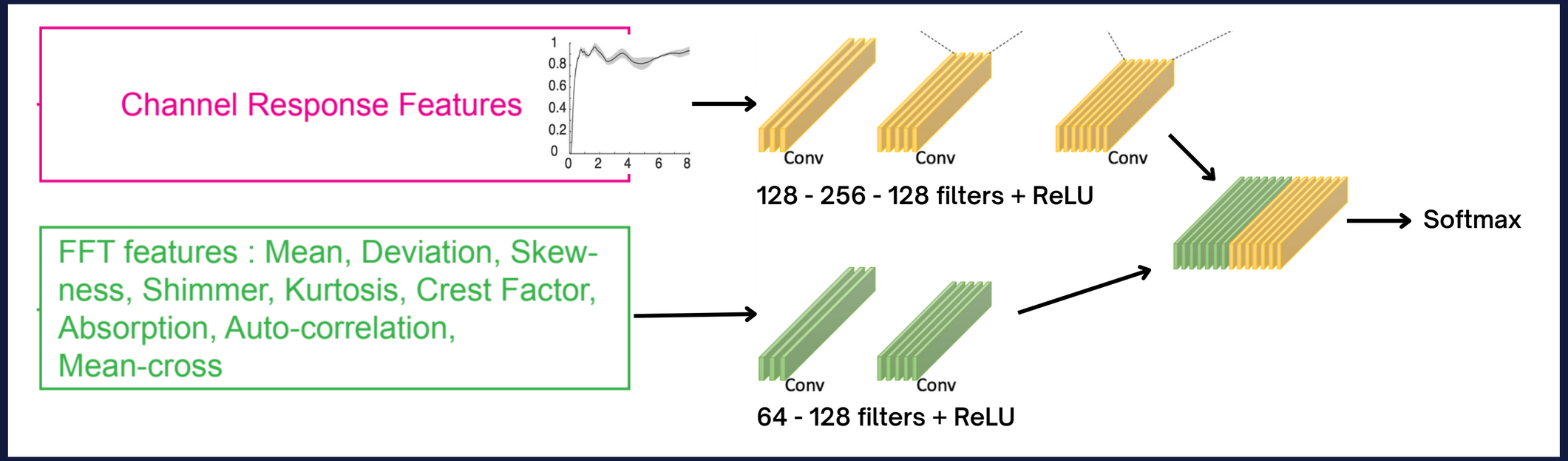


Implementation

Multi-view classifier

Problem:
2 dimensions of features not highly dependent -
> hard to feed to a single neural network

Solution:
Ensemble Classifier
-> backpropagation allows weight error correction, activation functions handle non-linearities, multi-layer captures low and high level features



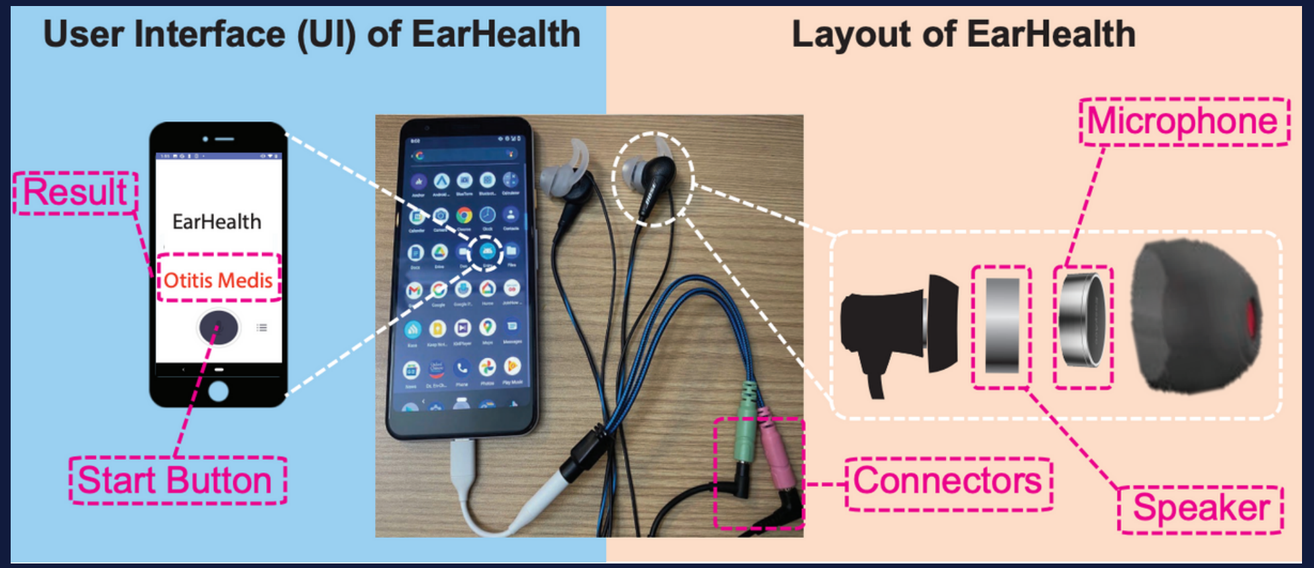
Experiment

Data of 92 subjects

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

Ground truth evaluated by clinical diagnosis

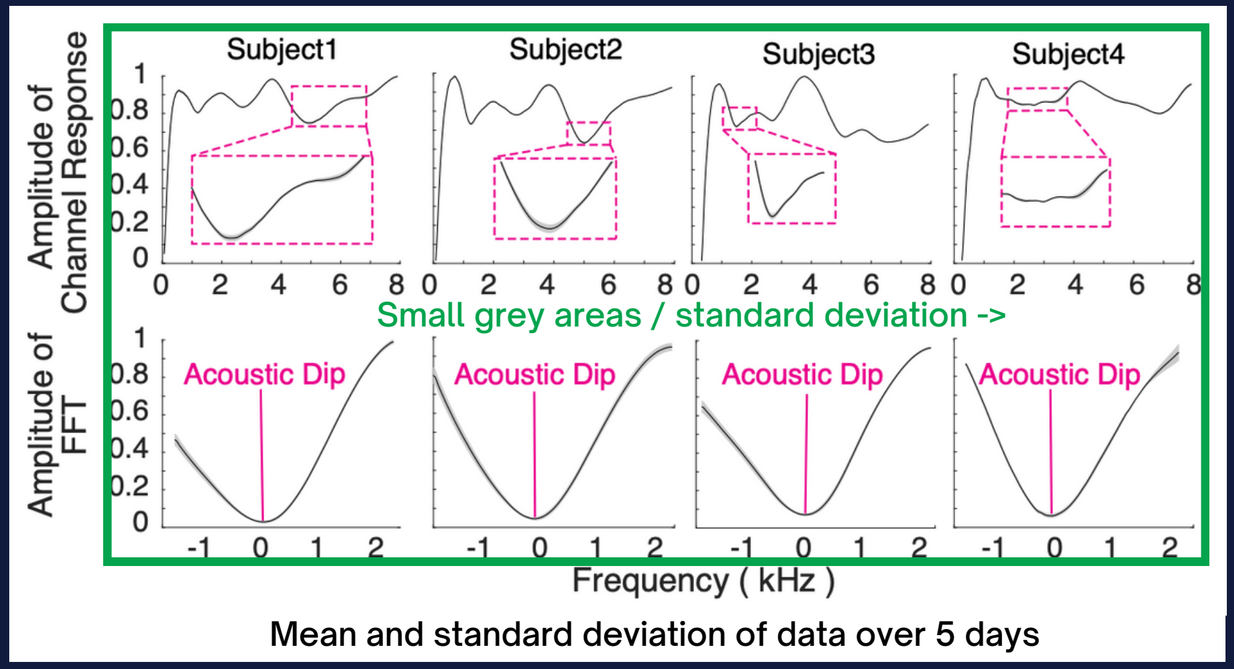
Sound stimuli = train of chirp (1s chirps 20 times without interval)



Evaluation

Checking for undesired behaviors

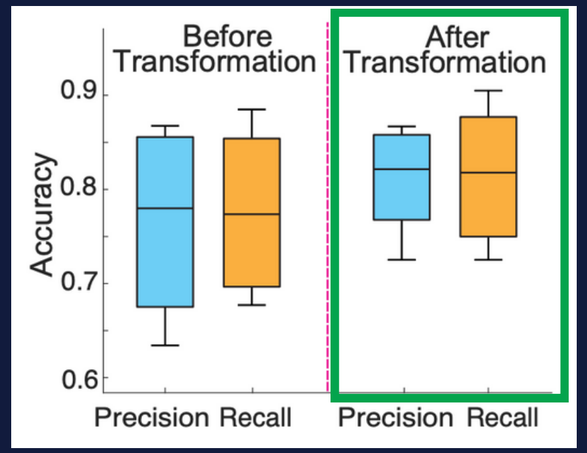
System stability and reliability



Mean and standard deviation of data over 5 days

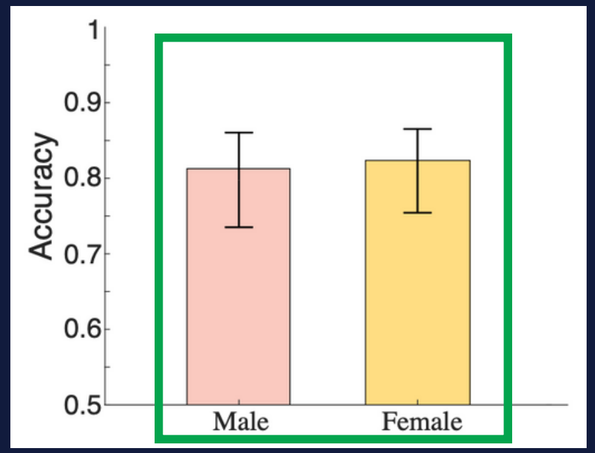
Ear canal uniqueness

Usefulness of data transformation



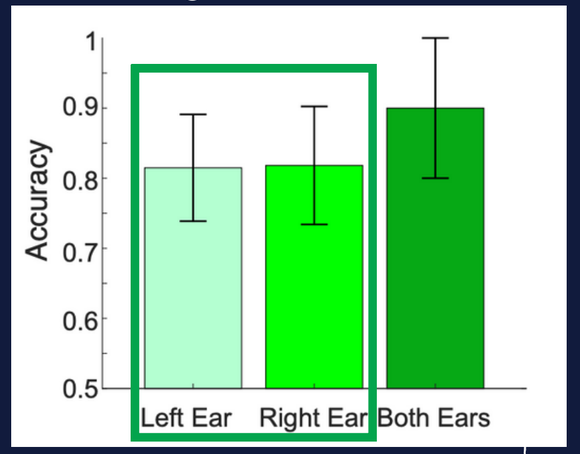
Gender

No influence



Left/right ear

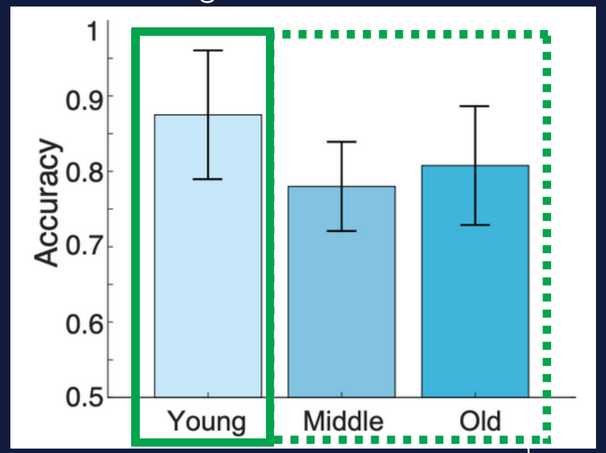
Unsignificant influence



2 times data generate more significant patterns

Age

Unsignificant influence



More normal ear conditions among young subjects

Evaluation

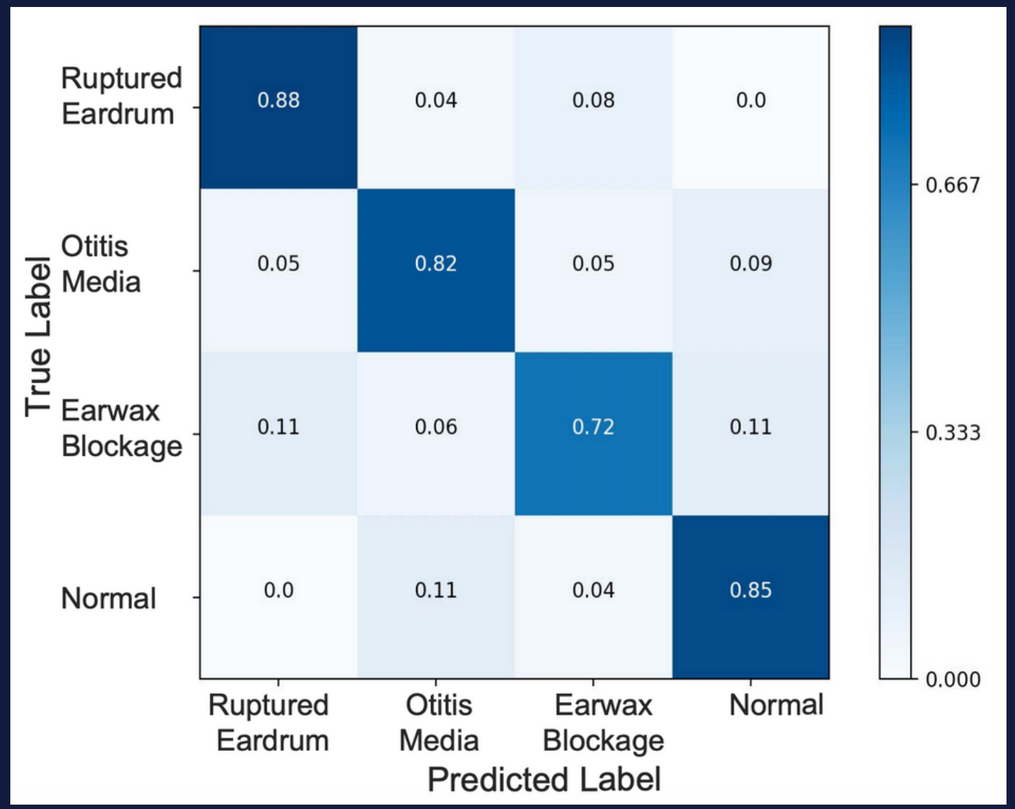
Overall performance and usability

Accuracy
+
Leave-one-out
cross validation

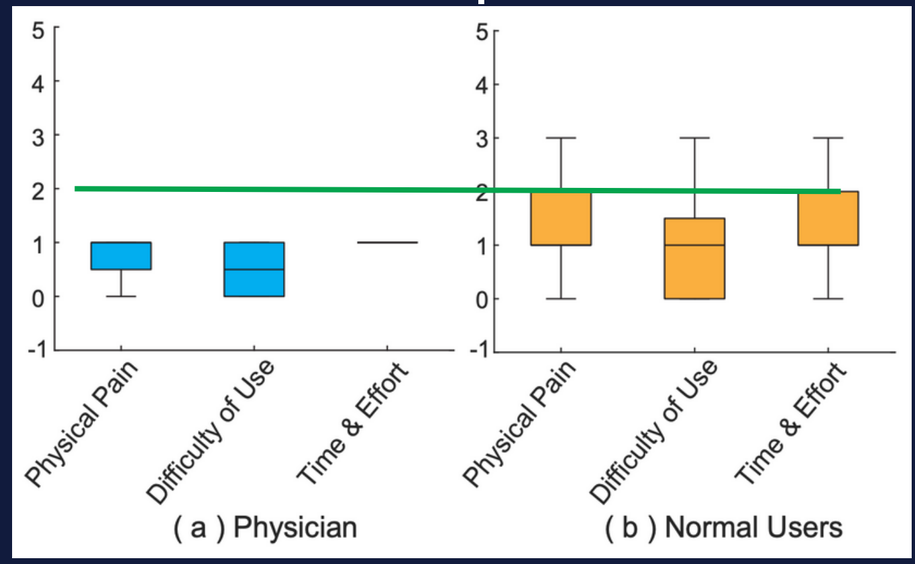
82.6%
overall

80.67%
for abnormal
condition

85%
for normal
condition



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

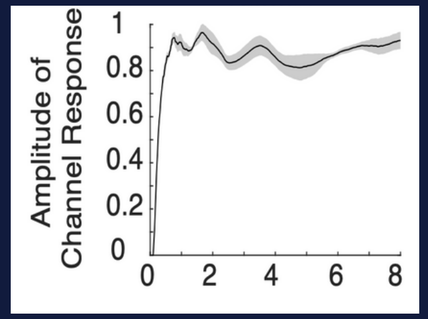
Related work

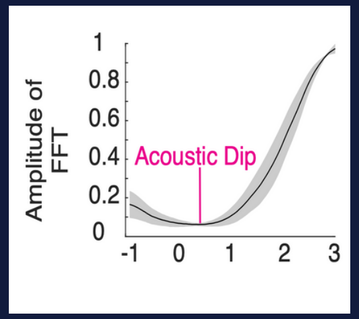
The idea

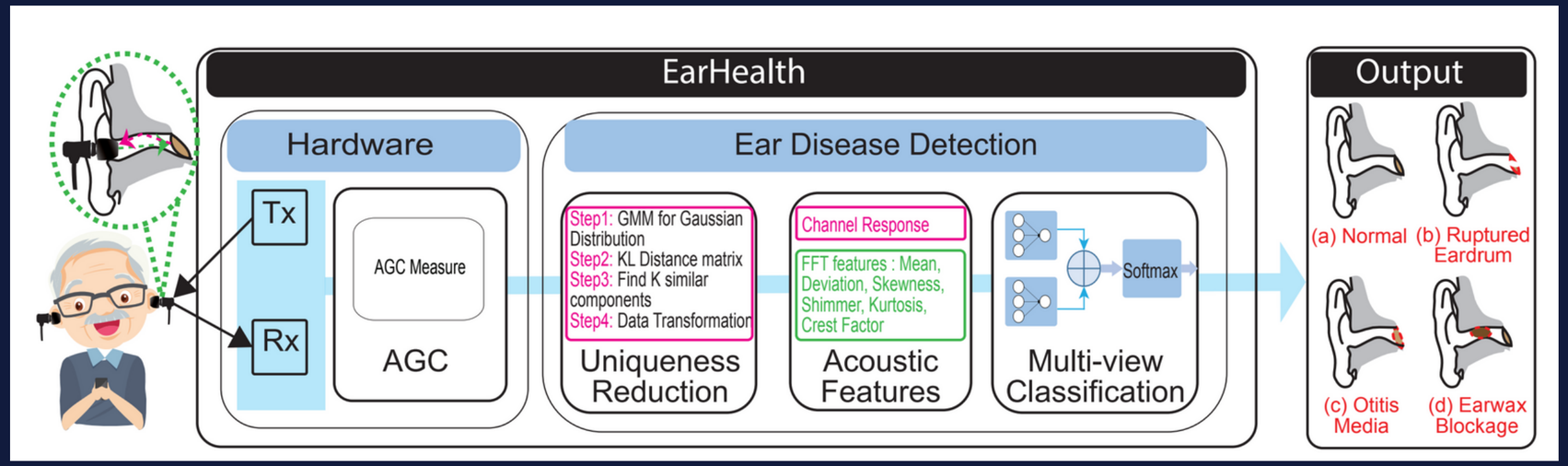
Implementation

Experiment

Evaluation







- Influence of the age neglictable, no influence of the gender, no difference between the left or right ear
- System stable and reliable
- Influence of ear canal diversity among subject highly 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