XI. Conference
of functional examinations of the lungs

Automatic examination
of breath sounds and cough

Hans-Jürgen Smith, Berlin, Germany

Zlín 19th – 20th May 2023

Lung sounds contain significant information about lungs and airways.

Ordinary auscultation has been a basic clinical study for assessment of pulmonary disorders since the discovery of the stethoscope by the French physician René T. H. Laënnec (1781-1826) in 1821.

A.R.A. Sovijärvi ARA, Vanderschoot J, Earis JE. Standardization of computerized respiratory sound analysis. Eur Respir Rev 2000; 10: 77, 585

Auscultation with the Stethoscope

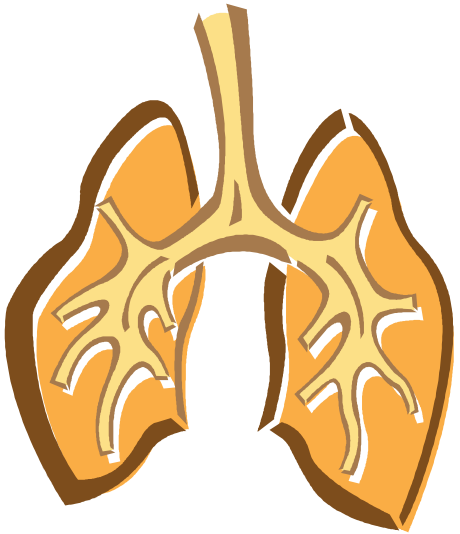
Listening to the internal sounds in the human body by using a stethoscope

Features and limitations of auscultation

- ⇨ Facilitation of diagnosis of common chest diseases

However

- ⇨ Requires professionally well-trained physician
- ⇨ Depend on ability in differentiation of sound pattern
- ⇨ Subjective procedure not really quantitative
- ⇨ Sounds are non-stationary and non-linear signals
- ⇨ Range of lung sounds depends on own hearing
- ⇨ Insufficient documentation
- ⇨ Influence of the stethoscope itself
- ⇨ Calibration?



A.R.A. Sovijärvi ARA, Vanderschoot J, Earis JE. Standardization of computerized respiratory sound analysis. Eur Respir Rev 2000; 10: 77, 585

Advantages of spectral lung sounds analysis

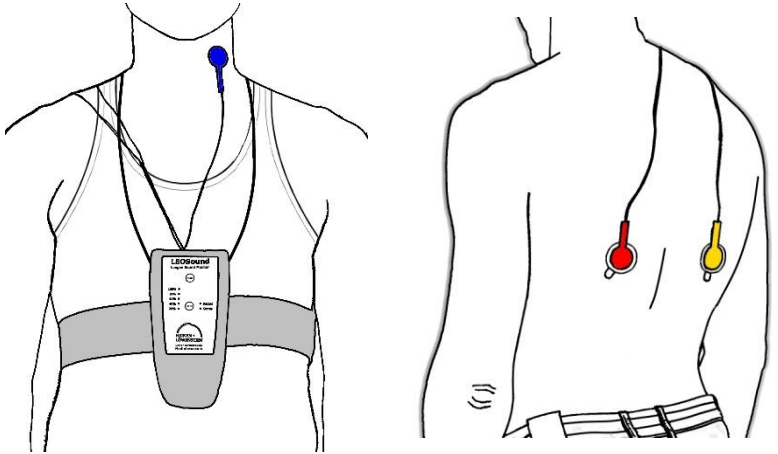
Schematic representation of the LEOSound application

Spectral lung sounds analysis

of the respiratory tract

- ⇨ Complements conventional diagnostics
- ⇨ Minimal patient co-operation
- ⇨ No limitation in age
- ⇨ Well known because standard procedure
- ⇨ Specific and differential contents
- ⇨ Objective in the assessment
- ⇨ Future oriented method / screening

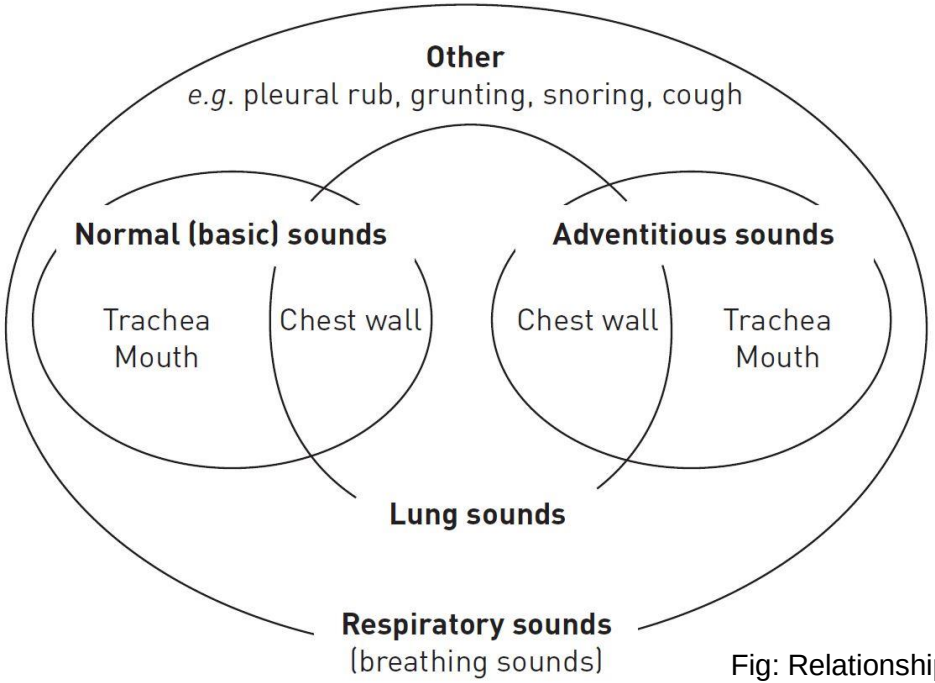
- ⇨ Assessment of cough



LEOSound: Tracheal sensor in blue. The thoracic sensors are placed dorsally over the left and right lungs (red and yellow).

Terms of breath sounds

EU project - Computerized Respiratory Sound Analysis (CORSA) in 2000



Types of sound

Upper airways ⇨ Snoring
⇨ Stridor
⇨ Cough

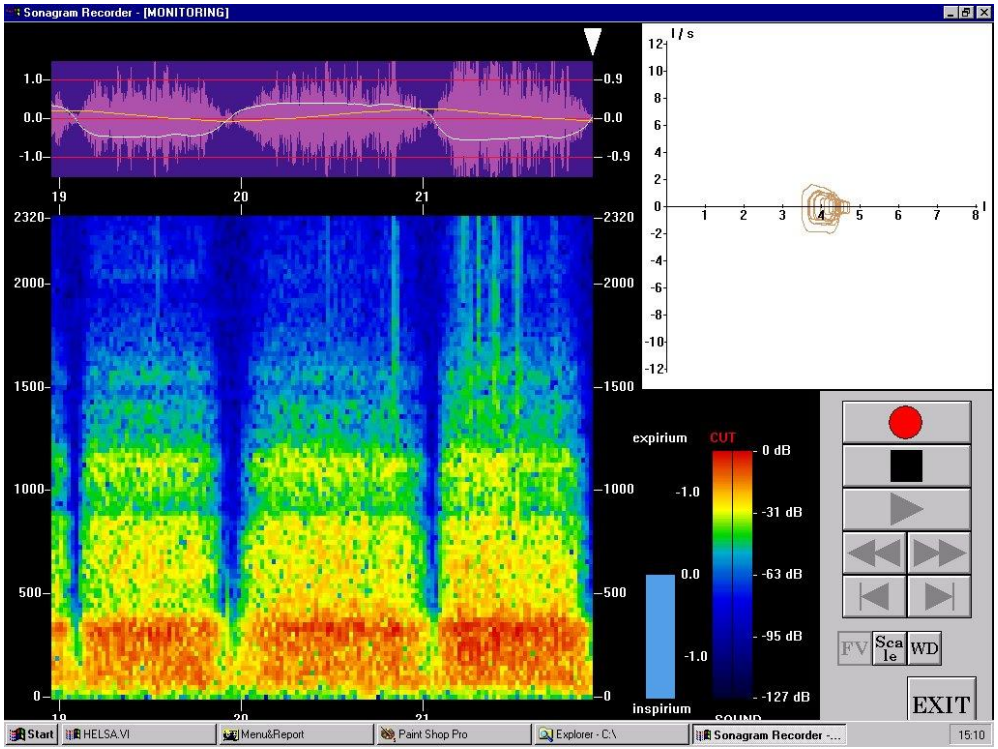
Lung sounds ⇨ Wheeze
⇨ Rhonchus
⇨ Crackles
⇨ Breath sounds

Fig: Relationship between the terms
breath sounds, adventitious sounds, lung sounds and respiratory sounds

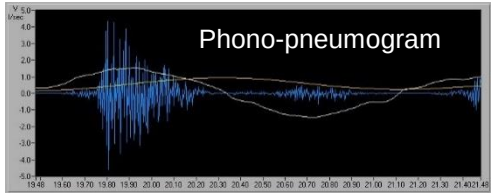
Sovijärvi ARA, et al. Definition of terms for applications of respiratory sounds. Eur Respir Rev 2000; 10: 77, 597–610
Pasterkamp H, et al. Towards the standardisation of lung sound nomenclature. Eur Respir J 2016; 47: 724–732

Lung sound analyser

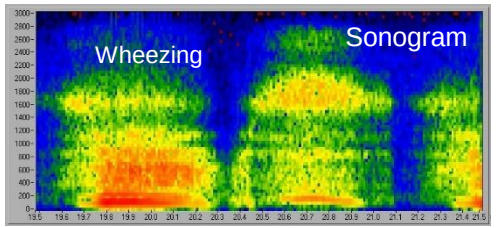
Features of HeLSA II – tidal and forced breathing



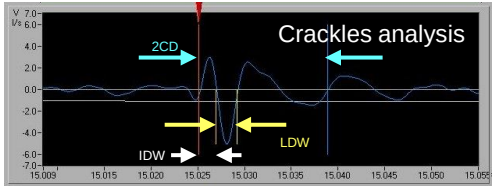
Phono-pneumo-gram



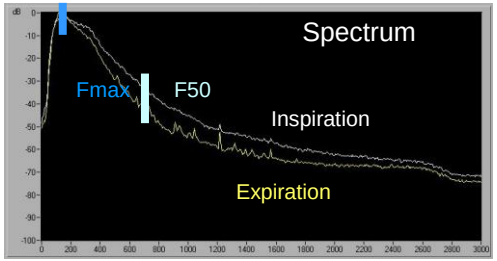
Sonogram



Crackles analysis



Spectrum



Problematic: Skill - noisy environment - missing standards.

Analysis of cough

Cough is a powerful respiratory reflex mechanism considered to have defensive capabilities aimed at removing mucus and foreign particles from the lower airways and preventing aspiration.

Guidelines and standards on cough

Clinical diagnosis and therapy

- 1998 - **1st international guideline on cough**
  Irwin RS et al. Managing cough as a defense mechanism and as a symptom: a consensus report of the American College of Chest Physicians. Chest 1998; 114 (Suppl.): 133S-181S
- 2006 - **2nd international guideline on cough**
  Irwin RS et al. Diagnosis and management of cough executive summary: ACCP evidence-based clinical practice guidelines. Chest 2006; 129 (Suppl.):1S-23S
- 2018 - **3rd international guideline on cough, updating from 2006**
  Irwin RS et al. Classification of cough as a symptom in adults and management algorithms; CHEST guideline and expert panel report. CHEST 2018; 153:196-209
- 2020 **ERS guidelines on chronic cough**
  Alyn H. Morice AH, et al. ERS guidelines on the diagnosis and treatment of chronic cough in adults and children. Eur Respir J 2020; 55: 1901136

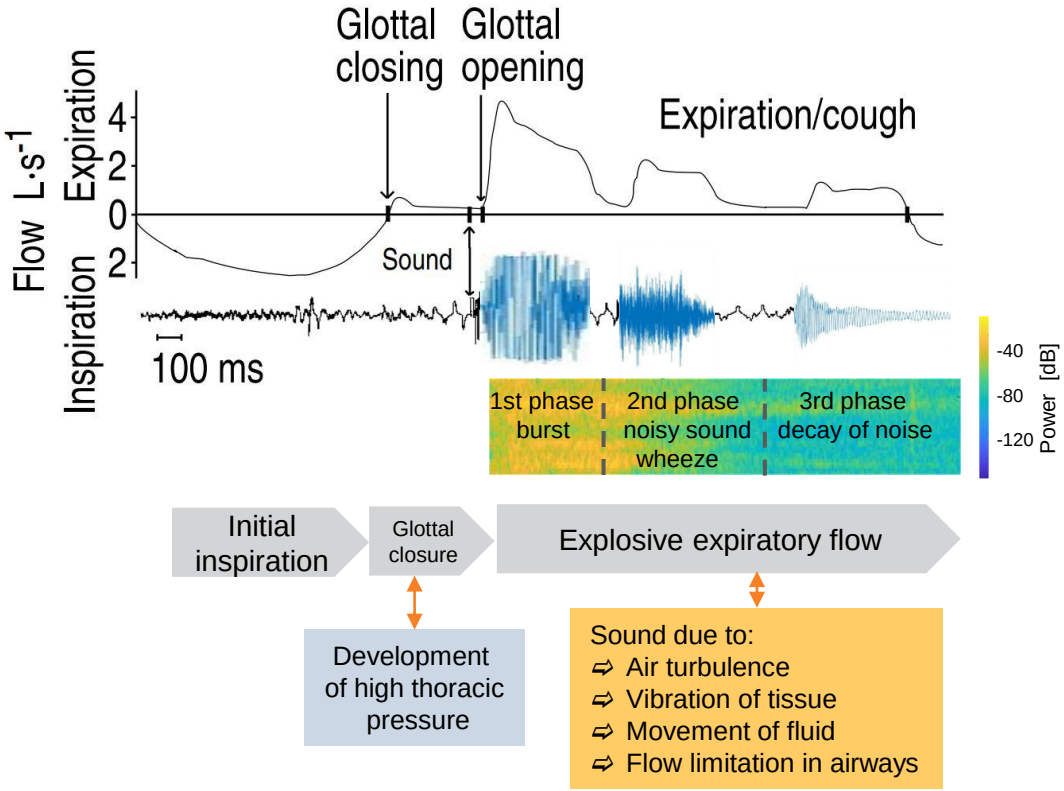
Automated detection of cough not included.

International Lung Sounds Association (ILSA)

- Physicians, engineers and other scientists involved in any aspect of research dealing with audible acoustics of the respiratory system
- Annual conferences 2012-2019

The sound of cough

Principle of sound generation



Typical cough sound with 2 or 3 phases

- **1st phase:** initial explosive phase with a very sharp increase in energy while air is released
- **2nd phase:** composed of a laminar airflow characterized by smaller amplitudes
- **3rd phase:** (not always present) is composed of a turbulent airflow that includes a pitch frequency caused by activation of the vocal cords

Eni M, et al. Cough detection using a non-contact microphone: A nocturnal cough study

Lee KK, et al. Sound: a non-invasive measure of cough intensity. BMJ Open Resp Res 2017; 4: e000178
Thorpe W, et al. Acoustic analysis of cough. 2017 Institute of Respiratory Camperdown, NSW 2050, Australia

Types of cough described

Analyse cough to diagnose, monitor, and facilitate respiratory treatment

Characteristics of cough

Laryngeal - tracheobronchial

wet - dry

ailment - voluntary

long term - short term

Dry cough

- ⇨ Tickly Cough
- ⇨ Hacking Cough

Wet Cough

- ⇨ Chesty cough
- ⇨ Phlegmy cough
- ⇨ Productive cough

Couth sounds

- ⇨ Wheezing cough
- ⇨ Barking cough
- ⇨ Whooping Cough

Duration of cough

- ⇨ Acute Cough
- ⇨ Subacute Cough
- ⇨ Persistent Cough

Sounds of cough

- ⇨ Wet or dry
- ⇨ Brassy or raspy
- ⇨ Ringing or barking
- ⇨ Whistling, whooped or wheezed

Singh VP, et al. Preliminary Analysis of Cough Sounds. Indian Institute of Technology Guwahati 2017
CoughPro Wellness-App by Marion Sereti July 30, 2022

Acoustic analysis of cough

Automated detection, differentiation and classification of cough

Automated cough detection

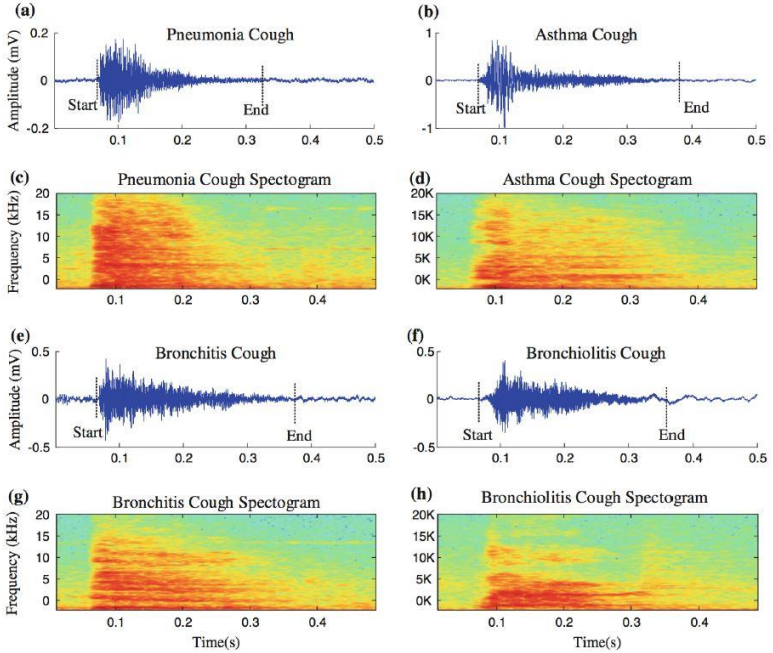
- Cough sound power and energy correlate strongly with physiological measures and subjective perception of cough strength
- An objective measure of cough evaluation – quality and quantity
- Can contribute to the diagnosis of respiratory diseases
- Can predict certain diseases
- Tracking of the progression of respiratory diseases
- Testing for reactions to different medications
- Screening diseases with AI-guided tools
- Saving manpower
- Studies can be performed anywhere, anytime and under easy conditions
- Free field cough-sound registration is possible

Cough sound is an important symptom of well over 100 diseases.

Thorpe W, et al. **Acoustic analysis of cough.** Institute of Respiratory Medicine; Co-operative Research Centre for Asthma. Camperdown, NSW 2050, Australia

Graphical presentation of cough

Dependence on disease



Disease based cough

- ⇨ Upper airway cough syndrome
- ⇨ Gastroesophageal reflux disease (GERD) cough
- ⇨ Asthma cough
- ⇨ Neurogenic cough
- ⇨ Smoker's cough
- ⇨ Iatrogenic drug-induced cough
- ⇨ Somatic cough syndrome
- ⇨ COVID-19 cough
- ⇨ Long covid cough

Phono-pneumograms and spectrograms provide the ground truth information of cough.

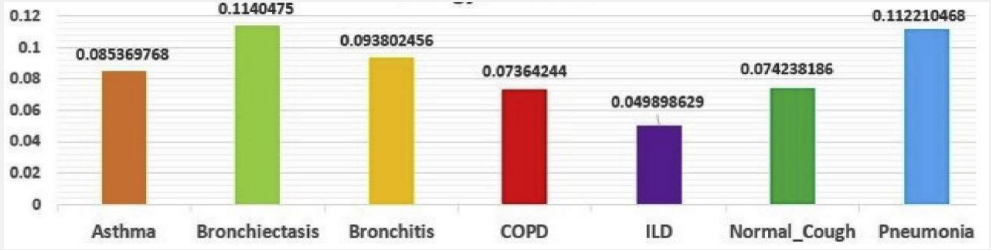
Saba E. Techniques for Cough Sound Analysis. University of Washington 2018.

Abeyratne U, et al. Cough Sound Analysis Can Rapidly Diagnose Childhood Pneumonia Annals of Biomedical Engineering 2013.

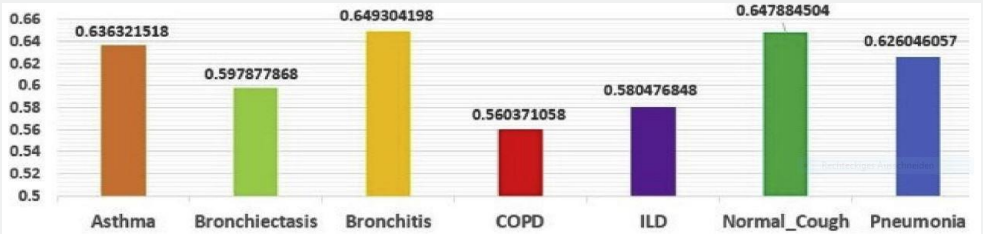
Automated classification of cough sounds

Cough is a most common symptom of respiratory diseases

Energy versus disease



Entropy (degree of disorder) versus disease



Machine learning

Model based on several (> 20) features.

For example:

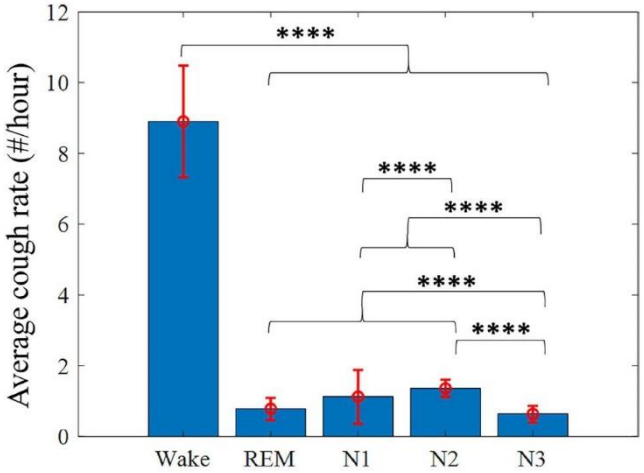
Cough ⇨ type,
⇨ duration,
⇨ energy
⇨ entropy

Cough and non-cough classifier applied.

Rudraraju G, et al. Cough sound analysis and objective correlation with spirometry and clinical diagnosis. Informatics in Medicine Unlocked 2020; 19: 100319

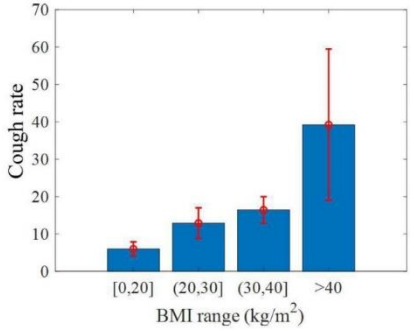
Cough detection in sleep

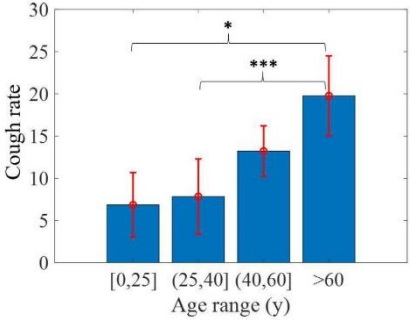
Application of a non-contact microphone

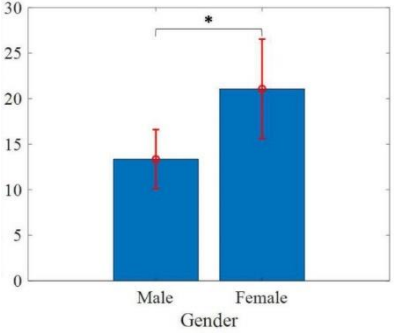


Average cough rate vs. wake/sleep stages

**** $p \leq 0.0001$







- Whole-night recordings of 89 subjects.
- 34 features to provide a good acoustic separation between coughs and other nocturnal sound events, like breathing, snoring, speech.
- DNN classifier demonstrated accuracy of 99.8% (86.1% sensitivity, 99.8% specificity, and 78.4% PPV)

Eni M, et al. Cough detection using a non-contact microphone: A nocturnal cough study.

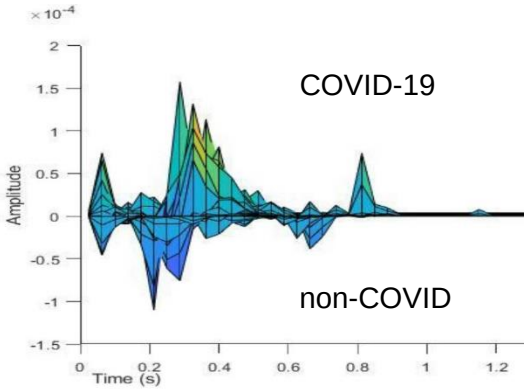
Analysing COVID-19

Cough is one of the important symptoms of COVID-19

- 2/3 of corona positive people have dry cough
- Coughs from COVID-19 individuals are:
  - longer in total duration
  - have more pitch onsets
  - higher periods
  - lower root mean square (RMS) energy.

- Interpretable **symptoms and types of cough** distinguished patients with COVID-19 from asthma, bronchitis and healthy individuals with 96.83% success.
- Virtual test opportunity by smartphones, away from the clinical and hospital environment.
- Artificial Intelligence technology

COVID-19 detection using cough sound is found to be cheap, effective and readily available.



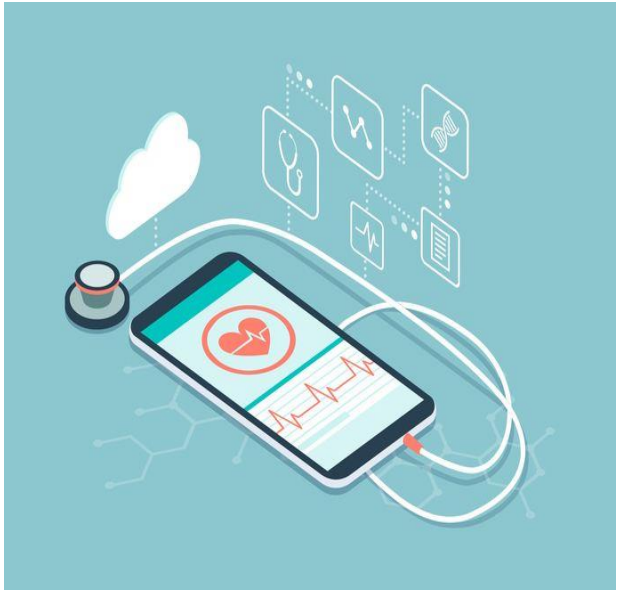
Power spectral density

Manshouri N. Identifying COVID-19 by using spectral analysis of cough recordings: a distinctive classification study. Karadeniz Technical University 2021.

Mobile phone app

Identification of symptoms through voices, breaths and coughs

Extensively applied in the management of the coronavirus pandemic



Algorithms used

- Machine learning
- Artificial intelligence (AI)
- Neurologic networks

Target

- AI-Smartphone App ‘listens’ to cough to diagnose the causative disease
- Home monitoring with non-contact microphone

Limitations of lung sounds and cough analysis

Physiologically and technologically as well as missing standards

Not every diseased person produces lung sounds or cough!

Limitations

- ⇨ Large intersubject variability
- ⇨ Missing standards of microphones and acquisitions conditions for sounds
- ⇨ Limited generalisations of the patterns observed in and between different disease states
- ⇨ Voluntary cough sounds show an inherent variability of the number of coughs and related lung volumes
- ⇨ Needs silent environment or noise detection / cancelling

Competition with the stethoscope.

Conclusions concerning automated analysis of lung sounds and cough

Cough is closely related to people's health.

- Complementary information conventional lung function can't provide
- The simple, non-invasive, non-hazardous, contactless and inexpensive nature of acquiring information about the respiratory system is attractive
- Power and energy are highly repeatable measures intraindividually
- Automated differentiation and classification of lung sounds and cough
- Computerised sound analysis, applying signal processing, artificial intelligence, deep learning and further algorithms
- On-line clinical diagnosis and follow up possible

Studies of sound with and without correlation to spirometry.