Detection of COVID-19 Through The Analysis of Vocal Fold Oscillations*

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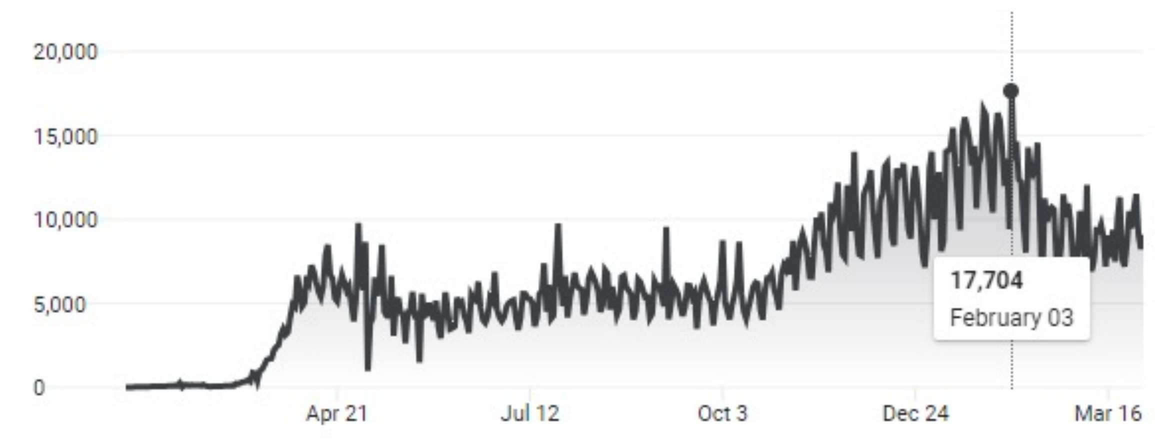
* This work was done at Carnegie Mellon University

COVID-19

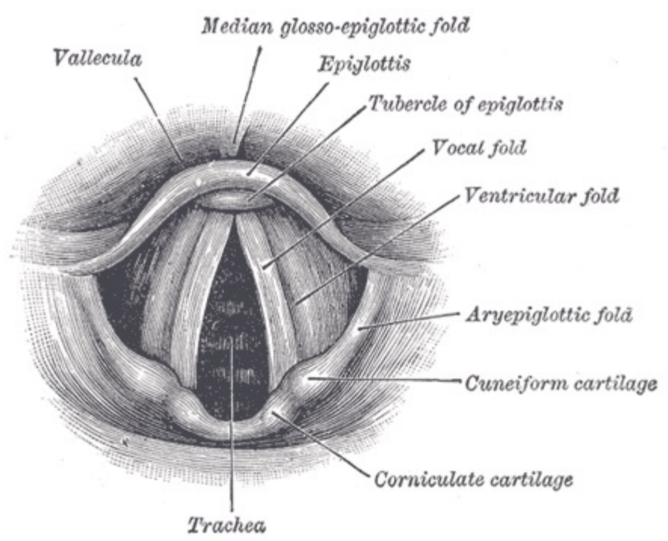
- Coronavirus disease 2019 (COVID-19) is a novel disease caused by SARS-Cov2 (severe acute respiratory syndrome coronavirus 2)
- As of today, *3 million* people died of the virus
- COVID-19 is known to impairs the functions of the lower and mid respiratory tract
- Testing is not easily accessible in some parts of the world and diagnosis takes few hours to 2 days



COVID-19 Daily Death Count

Phonation

- During vocalization, vocal folds vibrate to modulate the airflow
- Vocal folds vibrate at characteristic frequencies, called eigen-frequencies
- Intricate balance of the aerodynamic forces across glottis result in synchrony
- Any impairment, specially to lower and mid respiratory functions, can affect these forces
- This causes the folds to vibrate in an asymmetrical and asynchronized fashion



Laryngoscopic view of the vocal folds

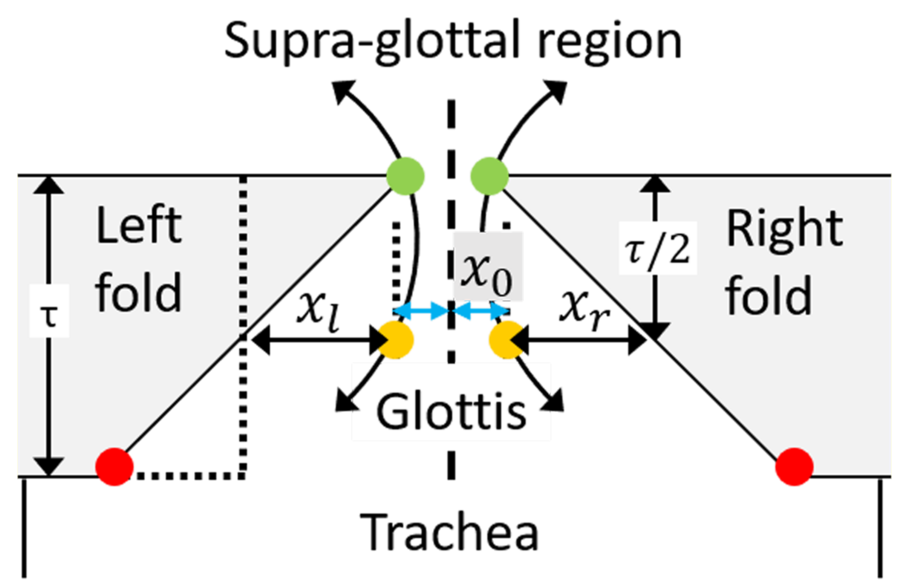
Vocal Fold Displacements

- In order to estimate to the displacements of the vocal folds, we utilize the 1-mass asymmetric body-cover model:

$$\ddot{x}_r + \beta(1 + x_r^2)\dot{x}_r + x_r - \frac{\Delta}{2}x_r = \alpha(\dot{x}_r + \dot{x}_l)$$

$$\ddot{x}_l + \beta(1 + x_l^2)\dot{x}_l + x_l + \frac{\Delta}{2}x_l = \alpha(\dot{x}_r + \dot{x}_l)$$

α is the coupling coefficient between the supra- and sub-glottal pressure
β incorporates mass, spring and damping coefficients
Δ is an asymmetry coefficient

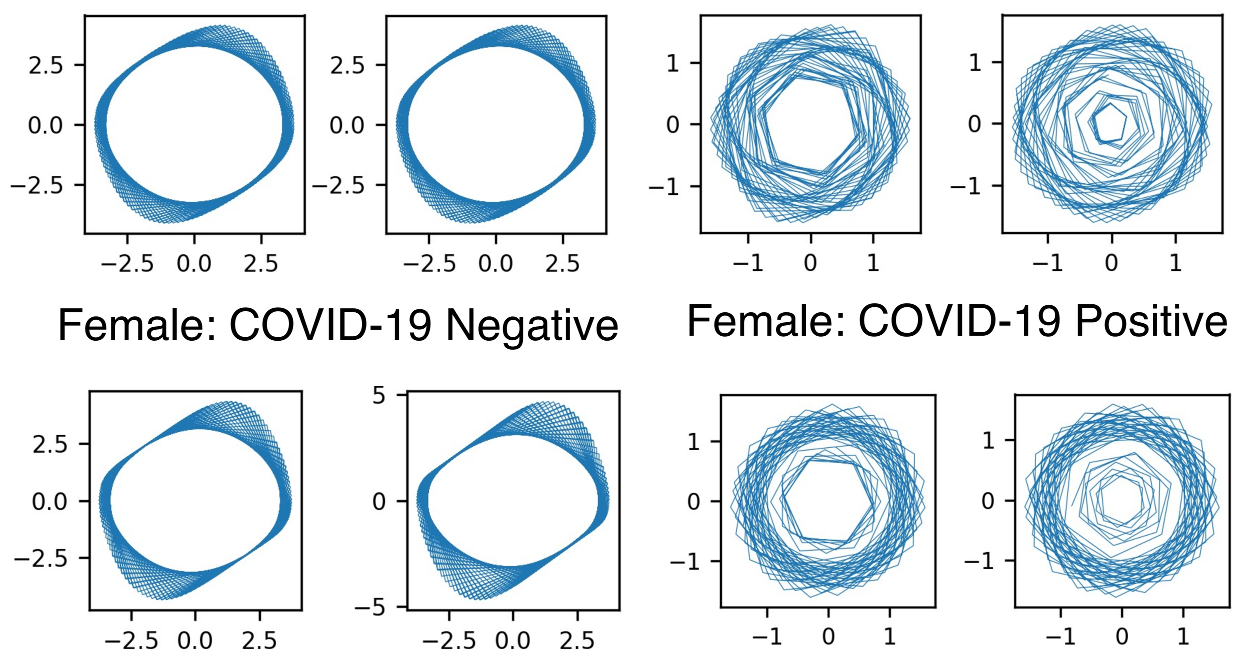


A cross sectional(frontal) view of the vocal folds. The folds have both horizontal and vertical (curved arrows) modes of oscillation.

Effect of COVID-19 on Voice

The following are phase trajectories for the left and right vocal folds respectively

where x-axis is the displacement and y-axis is the velocity



- Positive individuals exhibit complex trajectories and higher degree of asymmetry
- The vocal folds are unable to maintain the natural self-sustained vibrations required for vocalization.

Research Question

- Multiple studies have shown that COVID-19 affects the voice
- COVID-19 positive individuals reported changes in their voice and inability to produce voice normally

We ask the question:

Can we non-invasively characterize and detect COVID-19 from voice?

- Answering this question has the potential to enable rapid and scalable testing, reducing its prevalence and saving lives

Related Work

- At the time of this publication, work on detecting COVID-19 from voice, coughs and other respiratory sounds is recent and sparse
- Quatieri et. al attempted to detect COVID-19 but the study provided limited interpretations
- Brown et. al used crowdsourced voice recording utilizing deep learning approaches
- Huang et. al showed that COVID-19 patients were observed to have abnormal breath sounds like crackles, asymmetrical vocal resonances and indistinguishable murmurs

ADLES

- We ADLES algorithm to estimate the parameters of the model
- This is achieved by minimizing the error between the glottal flow waveform obtained by inverse filtering, and the vocal fold oscillations predicted by the model as its parameter space is sampled

ADLES primary formulation

$$\min \int_0^T (u_0(t) - u_0^m(t))^2 dt$$

$$\Leftrightarrow \min \int_0^T \left(\tilde{c}d(2x_0 + x_l(t) + x_r(t)) - \frac{A(0)}{\rho c}\mathcal{F}^{-1}(p_m(t))\right)^2$$

$$\text{s.t.} \quad \ddot{x}_r + \beta(1 + x_r^2)\dot{x}_r + x_r - \frac{\Delta}{2}x_r = \alpha(\dot{x}_r + \dot{x}_l)$$

$$\ddot{x}_l + \beta(1 + x_l^2)\dot{x}_l + x_l + \frac{\Delta}{2}x_l = \alpha(\dot{x}_r + \dot{x}_l)$$

$$x_r(0) = C_r, x_l(0) = C_l, \dot{x}_r(0) = 0, \dot{x}_l(0) = 0$$

Notation

$u_0(t)$: Measured glottal flow
$u_0^m(t)$: Estimated glottal flow
$\tilde{c}$: Air particle velocity
A: Vocal tract area function
$\mathcal{F}^{-1}$: Inverse filter
α, β, Δ: Model parameters where

- α is the coupling coefficient between the supra- and sub-glottal pressure
- β incorporates the mass, spring and damping coefficients of the vocal folds
- Δ is an asymmetry coefficient.

Use ADLES to iteratively estimate the model parameters α, β, Δ

Results

We used extended recordings of vowels /a/, /u/, /i/ collected under expert clinical supervision

The dataset contains 19 individuals:

- 10 females - 5 diagnosed with COVID-19
- 9 males - 4 diagnosed with COVID-19

Each utterance is segmented using a window of 50ms with a shift of 25ms, resulting in a total of 3835 frames

Classifiers	LR	NL-SVM	DT	RF	AB
ROC-AUC	0.825	0.789	0.803	0.794	0.812
STD	0.032	0.037	0.081	0.060	0.064

Table 1: Performance of different classifiers in a stratified 3-fold cross-validation experiment.

	/a/	/i/	/u/	/a/+/i/	/a/+/u/	/i/+/u/
AUC	0.653	**0.912**	0.877	0.728	0.784	0.901
STD	0.119	0.023	0.035	0.089	0.038	0.023

Table 2: Performance of logistic regression on extended vowels and their combinations.