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

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*The work was done at Carnegie Mellon University

Coronavirus Disease 2019 (COVID-19)

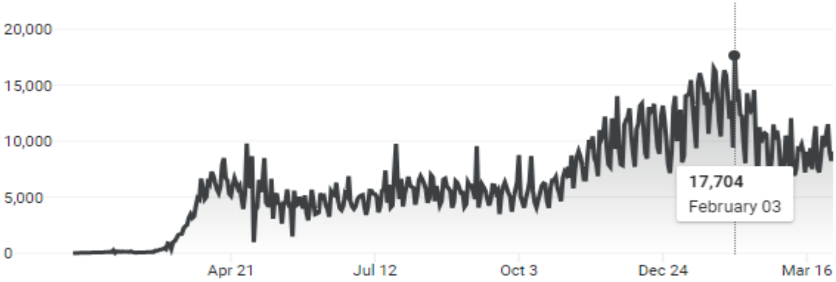

Figure: COVID-19 daily death count [Wikipedia, 2021]

- 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 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

Research Problem

- Multiple studies have shown that COVID-19 affects the voice [Schuller et. al., 2020]
- COVID-19 positive individuals reported:
  - Changes in their voice
  - 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

Phonation

- Phonation is the primary source of vocalization
- During vocalization, vocal folds vibrate to modulate the airflow
- Vocal folds have characteristic frequencies at which they vibrate, called eigen-frequencies
- During phonation, the two vocal folds synchronize at one of their many 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

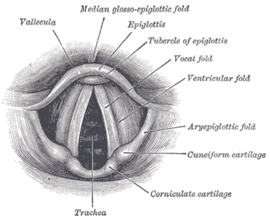

Figure: Laryngoscopic view of interior of larynx

Related Work

- Work on detecting COVID-19 from voice, coughs and other respiratory sounds is recent and sparse [Schuller et. al., 2020]
- [Quatieri et. al., 2020] attempted to detect COVID-19 but the study provided limited interpretations
- [Brown et. al., 2020] used crowdsourced voice recording utilizing deep learning approaches
- [Huang et. al., 2020] showed that COVID-19 patients were observed to have abnormal breath sounds like crackles, asymmetrical vocal resonances and indistinguishable murmurs

Vocal Fold Oscillation Model

- Several mathematical models of phonation proposed in the past decades
- We utilize the 1-mass asymmetric body-cover model [Lucero et. al., 2015]
- This model is able to capture the asymmetry between the left and right vocal folds

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

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

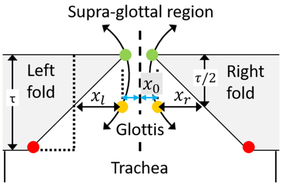

Figure: A cross sectional(frontal) view of the vocal folds. The folds have both horizontal and vertical (curved arrows) modes of oscillation.

Vocal fold parameter estimation

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

Effect of COVID-19

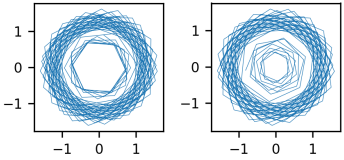

Figure: Male Positive

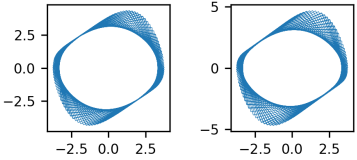

Figure: Male Negative

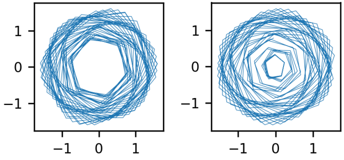

Figure: Female Positive

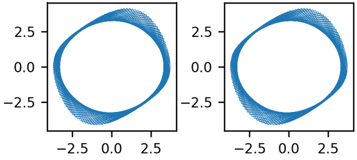

Figure: Female Negative

Detection of COVID-19

In this study, 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.

For each frame, we estimate α, β, and Δ as well as the residue R using ADLES and use them as features to simple classifiers.

Results

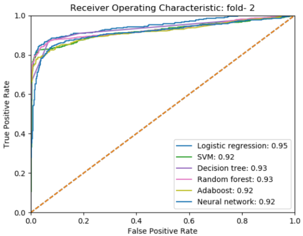

Figure: ROC curve using different classifiers for a single fold

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

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

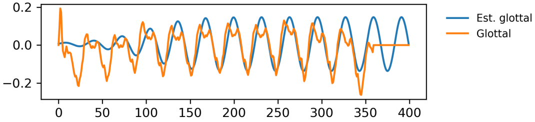

Figure: Estimated vocal fold oscillations compared to the estimated glottal flow waveform of a subject

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

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

Conclusion

COVID-19 adversely affects the motion of the vocal folds:

- Phase trajectories indicate a high degree of asynchrony and asymmetry
- Limited range of motion

We showed that it is possible to achieve a high ROC-AUC using just a single phonated vowel `/i/`.

Future Work

- Explore more complex model to estimate the oscillations of vocal folds
- Contrast the anomalous COVID-19 oscillations to different pathologies
- Study the effect of other pathologies on the process of voice production

References

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COVID-19 pandemic data

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Thank you for listening!

And please stay safe