RuHuman: A Resilient Multimodal AI-Powered Audio Verification System

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ECE202A Embedded Systems @ UCLA

Motivation and Objectives

- Audio deep fakes are becoming more easily spoofable with the advent of generative AI.
    - Growing number in <u>deep fake crimes</u>
- RuHuman evaluates existing audio liveness detection systems that exploit multiple audio modalities.
- The Objectives of this RuHuman Are:
    - Evaluating different audio liveness detector architectures against state of the art voice cloners.
    - Developing a user interface to make gateway devices (e.g. phone) easily verify with their microphones

Mom warns of AI voice cloning scam
119K views • 8 months ago
Good Morning America
ABC News' Erielle Reshef shares an urgent warning from

Previous/Related Work

- ASVSpoof is a dedicated challenge that to develop audio spoofing classifiers. Three main challenges are PA, LA, and DF (RuHuman focuses on LA).
- Researchers take advantage of various encodings (STFT, MFCC, CQCC) to augment the training resolution of the audio sample.
- UCLA NESL developed ResNet models with different embeddings and performed model fusion to minimize ASV/CM loss metrics in ASVSpoof 2019.
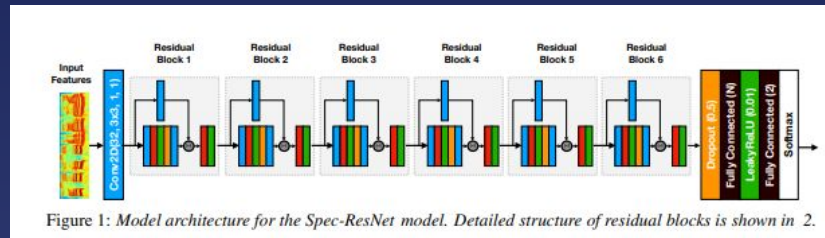

Automatic Speaker Verification and Spoofing Countermeasures Challenge

Figure 1: Model architecture for the Spec-ResNet model. Detailed structure of residual blocks is shown in 2.

Novelty of Project

- Datasets used for training in ASVSpoof2019 LA challenge were in a controlled environment, insusceptible to 'out in the wild' samples
- RuHuman investigates the performance of different detector architectures when additive noise is mixed in with the suspected audio sample.
- Additionally, RuHuman implements an interactive user interface that allow for a wide range of computing (from a cell phone to a computer workstation) to access multiple detector models with just an HTTP Post Request.

RuHuman Audio Verification System

Check if Your Audio is Produced by an AI:

Option 1: Record a Live Sample

Record

Option 2: Upload a Recording

Choose File No file chosen

Verify Audio Reset

Choose a Detector Model: Tortoise

4

Background: Audio Feature Extractions

STFT (Short-Time Fourier Transform): Compute FFT over a window, use log to plot Spectrogram.

LFCC (Linear-Frequency Cepstral Coefficients): Map frequency powers through a linear filter bank then take DCT of log of filter coefficients
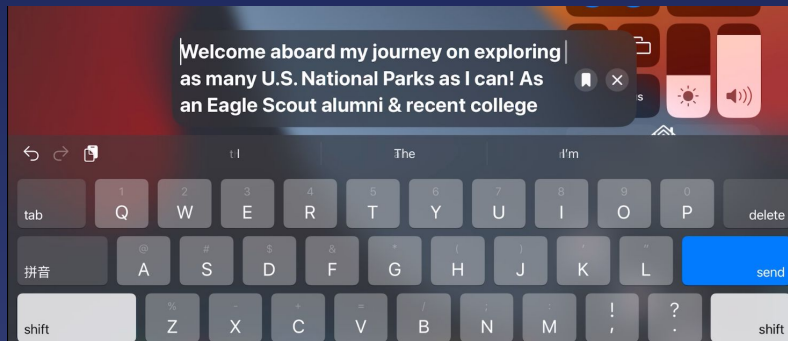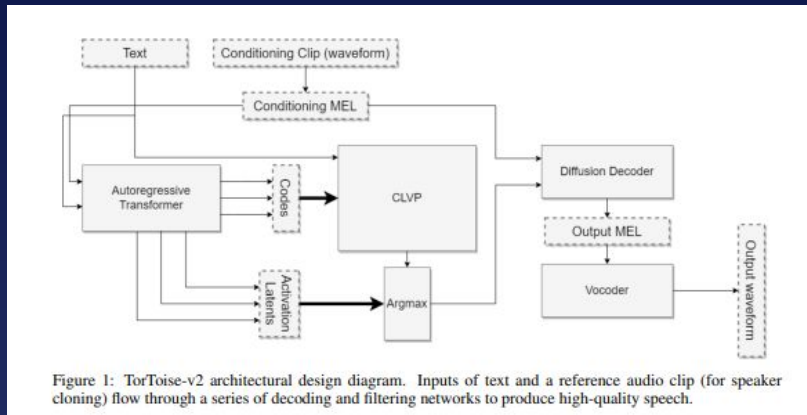
MFCC (Mel-Frequency Cepstral Coefficients): Map frequency powers through a mel filter bank (tuned for humans), then take DCT of coefficients.

CQCC (Constant Q Cepstral Coefficients): Uses CQT basis for cepstrum. More spectro/temporal resolution at low/high frequencies.
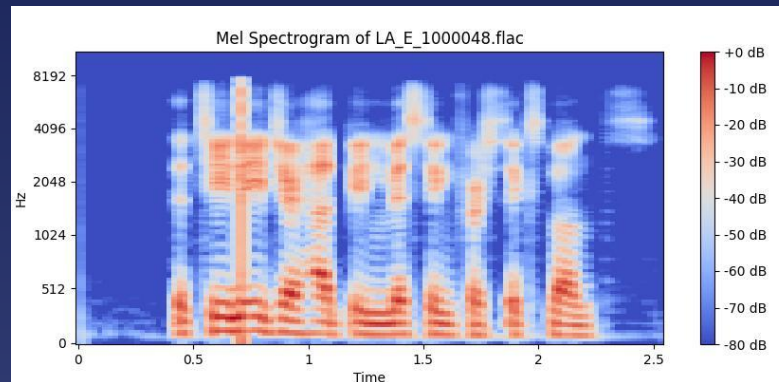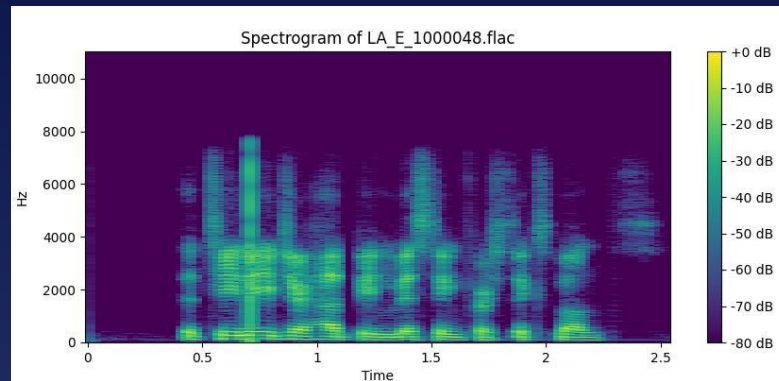
Overview of Voice Cloners

- **Tortoise:** A voice cloner using Autoregressive Diffusive decoder with DDPM noise schedulers.
    - Pre-trained on 49,000 hours of audio clips from podcasts/videos.
- **Apple Personal Voice:** A proprietary personalized voice synthesizer that is trained by using 15 mins of live utterance
    - Trained locally on iOS device, use text to speech to synthesize audio.
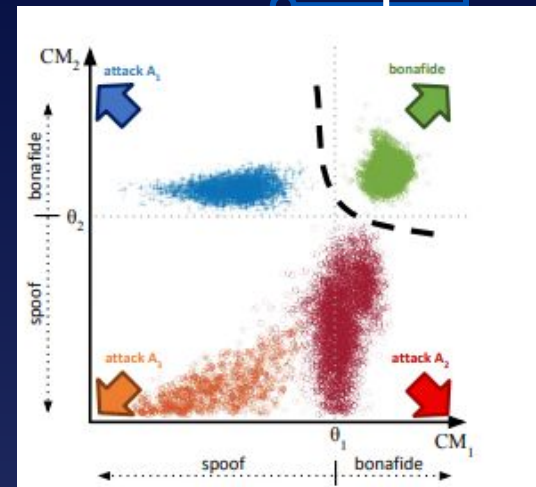   - Aside: Not easily exportable, must use screen recorder to grab audio.

Figure 1: TorToise-v2 architectural design diagram. Inputs of text and a reference audio clip (for speaker cloning) flow through a series of decoding and filtering networks to produce high-quality speech.

Overview of Voice Detectors

Baseline ASVSpoof Models:

- **LFCC-GMM:** A Two-Class Gaussian Mixture Model with LFCC input. 70-Channel Linear Filters. Outputs LLR between bonafide & spoof.
- **CQCC-GMM:** A Two-Class Gaussian Mixture Model with CQCC input. Features are 1st 19 Coeff. Outputs LLR between bonafide & spoof.
- **RawNet2:** An End to End Neural Network using mel sinc filters. Outputs two-class likelihood between bonafide and spoof.
- All Baseline models trained with ASVSpoof2019 Training Set (~25380 Samples, 20/107 Distinct Speakers from total set)

In the Wild Models:

- **Tortoise:** An Audio Mini Encoder Classifier. Outputs probability on whether an audio sample was generated by TortoiseTTS.
  - Trained on same data used by detector (49,000 hours of podcasts/videos from internet).

Overview of User Interface

- Web Server Implemented in Python Flask to serve many gateway devices that have internet access.
- Users can verify their audio sample in 2 ways:
  - **1.** Users record a live sample client-side by using *getUserMedia()* from Javascript, which then is saved to a blob.
  - **2.** Users upload a pre-recorded audio file from their device to the HTML form to post.
- Users upload data via HTTP request post to server.
- File is stored and pass through detector via refactored callable Python functions (GMMs: *matlab.engine*)
- Dashboard displays uploaded audio (verifying it's on the server), in addition to visualizing it's encodings with *librosa* and outputting metrics of verification.

RuHuman Audio Verification System

Check if Your Audio is Produced by an AI:

Option 1: Record a Live Sample

`Record`

Option 2: Upload a Recording

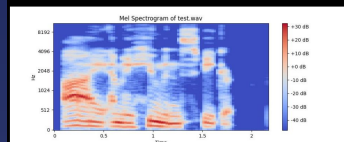`Choose File` `No file chosen`

`Verify Audio` `Reset`

Choose a Detector Model: `Tortoise`

Your Uploaded Audio Sample: (test.wav)

▶ 0:00 / 0:02 🔊 ⋮

Features:

Mel Spectrogram of test.wav

Detector Model: Tortoise (Detected in 0.16 seconds)

Probablity of Being Spoofed by Generative AI via Tortoise Model: 99.98%

Return to Homepage
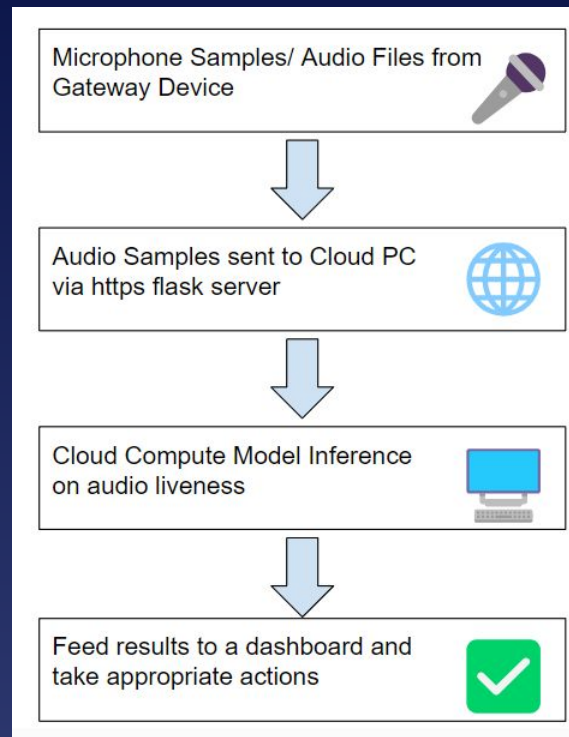
Metrics of Evaluation

- **t-DCF:** A custom cost function that weighs between predefined ASV scores (from organizers), speaker priors, and CM scores provided by the detector architecture.
- **EER:** The likelihood threshold at which the miss rate and the false alarm rate equate.
- **Computation Time:** The duration for a single audio sample to be verified.
    - Ideally in a live setting should be less than duration of the sample.
- Objective is to minimize all metrics for accuracy and efficiency in live settings.

$$
\begin{aligned}
\text{t-DCF}(s, t) = \; & C_{\text{miss}}^{\text{asv}} \cdot \pi_{\text{tar}} \cdot P_{\text{a}}(s, t) \\
& + C_{\text{fa}}^{\text{asv}} \cdot \pi_{\text{non}} \cdot P_{\text{b}}(s, t) \\
& + C_{\text{fa}}^{\text{cm}} \cdot \pi_{\text{spoof}} \cdot P_{\text{c}}(s, t) \\
& + C_{\text{miss}}^{\text{cm}} \cdot \pi_{\text{tar}} \cdot P_{\text{d}}(s).
\end{aligned}
$$

- $C_{\text{miss}}^{\text{asv}}$ – cost of ASV system rejecting a target trial.
- $C_{\text{fa}}^{\text{asv}}$ – cost of ASV system accepting a nontarget trial.
- $C_{\text{miss}}^{\text{cm}}$ – cost of CM rejecting a human trial.
- $C_{\text{fa}}^{\text{cm}}$ – cost of CM accepting a spoof trial.

Technical Approach

- **Phase 1: Investigation of Additive Noise Sources** (ASVSpoof Submissions Only)
    - Work with each baseline detector to produce metrics on the ASVSpoof2021 Evaluation Set (181,566 samples, 67 Distinct Speakers, 37 F, 30 M).
    - Inject each audio sample in the evaluation set with additive white gaussian noise (SNR = 50).
    - Recompute metrics with infected evaluation set and compare scores.
- **Phase 2: Deployment of User Interface**
    - Send/receive audio from client/gateway with multiple upload options.
    - Refactor detectors to be callable functions with audio path argument.
    - Show audio features and results on dashboard.

Microphone Samples/ Audio Files from Gateway Device

Audio Samples sent to Cloud PC via https flask server

Cloud Compute Model Inference on audio liveness

Feed results to a dashboard and take appropriate actions

Primary Metric Metric: t-DCF & EERs

Detector Architecture (Normal)	Pooled t-DCF	Pooled EER (%)
Baseline LFCC-GMM (MATLAB)	0.5758	19.30
Baseline CQCC-GMM (MATLAB)	0.4964	15.62
Baseline RawNet2 (Python)	0.4255	9.49

Detector Architecture (AWGN)	Pooled t-DCF	Pooled EER (%)
Baseline LFCC-GMM (MATLAB)	0.8527	41.33
Baseline CQCC-GMM (MATLAB)	0.7609	31.99
Baseline RawNet2 (Python)	0.3317	7.23

Secondary Metric: Computation Time

Detector Architecture	Average Computation Time per Sample (s)
Tortoise Audio Mini Encoder (Python)	0.22
Baseline LFCC-GMM (MATLAB)	0.18
Baseline CQCC-GMM (MATLAB)	0.27
Baseline RawNet2 (Python)	0.30

*on average each sample was approximately 3-5 seconds long

Demo
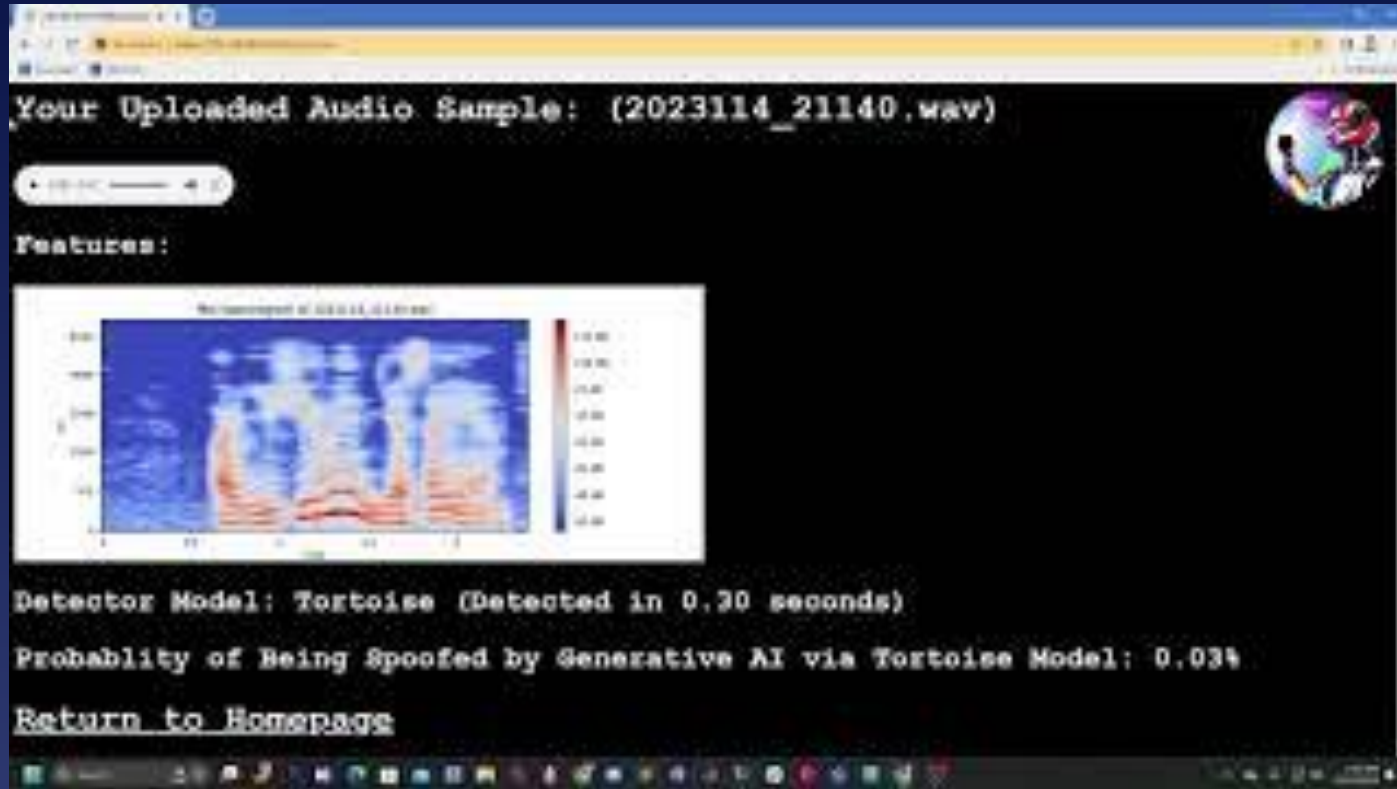
Conclusion & Future Directions

Conclusion:

- Primary evaluation from phase 1 indicates that additive noise can be injected to GMMs enhance a plausible spoofing attack to being successful.
    - Metrics actually went lower for RawNet2, perhaps the initial layer of Mel Sinc Filters mitigated the effect of AWGN.
- All detectors were able to detect an audio samples within a second, making them usable for liveness detection.
- User Interface was deployed and easily accessible from gateway devices.
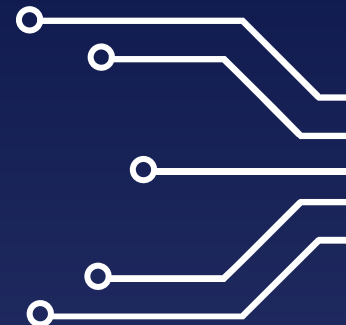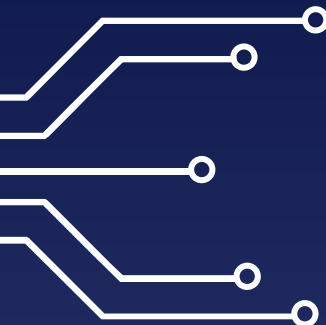
Future Directions:

- Preprocess audio samples with denoising to isolate speaker from noise before being sent to spoof detection model.
- Perform embedded actions on classifier outputs (e.g. turn a light red/green)
- Audio spoofing detection can be fused with other modalities of liveness detection (i.e. video deep fake detection) for a complete system. May experiment with this pipeline over winter break on a separate branch.

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Thanks for Listening!
Any Questions?