A Privacy-Preserving Unsupervised Speaker Disentanglement Method for Depression Detection from Speech

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I. Introduction

- ➔ Automated depression detection using speech can be helpful to clinicians and patients.
- ➔ Challenges: Patient privacy ⚠
  - ◆ Patients can be identifiable if speaker ID information is included (ex. Membership inference attacks can occur)
- ➔ Previous work on privacy-preservation
  - ◆ Adversarial methods - > Unstable loss maximization
  - ◆ Need Speaker labels for training data -> Supervised
  - ◆ Speaker prediction branch needs additional parameters -> Inefficient
- ➔ Solution -> Cosine similarity minimization between speaker and depression embedding spaces
  - ◆ No Speaker labels used: Unsupervised!
  - ◆ No additional parameters: Efficient!

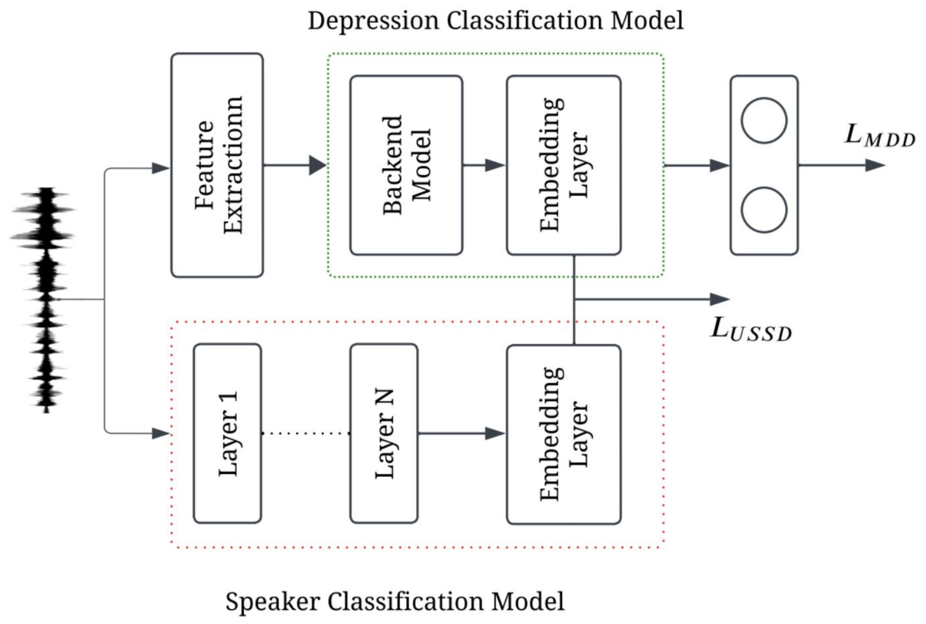
II. Proposed Method

Background: Adversarial Learning (ADV [16])

- ➔ Loss Min. - Max.
  - ◆ Depression prediction Loss L_{MDD} - minimized.
  - ◆ Speaker prediction Loss L_{SPK} - maximized.
  - ◆ Gradient reversal disentangles the speaker identity from depression characteristics.

$$L_{total-ADV} = L_{MDD} - \alpha \cdot L_{SPK-ADV}$$

Unsupervised Speaker Disentanglement (USSD)



Off-the-shelf Speaker Classification Model [35]
(No finetuning or retraining)

Key Idea -

- ➔ For utterance X, get speaker and depression embeddings

$$H_{MDD_X} = \theta_{MDD}(X)$$
$$H_{SPK_X} = \theta_{SPK}(X)$$

- ➔ Minimize Cosine similarity between the two embedding spaces.

$$Y_{pred_{(i,j)}} = \frac{H_{MDD_{X_i}} \cdot H_{SPK_{X_j}}}{||H_{MDD_{X_i}}|| \cdot ||H_{SPK_{X_j}}||}$$

$$Y_{target_{(i,j)}} = 0$$

$$L_{USSD} = MSE(Y_{pred}, Y_{target})$$

$$L_{total-USSD} = L_{MDD} + \alpha \cdot L_{USSD}$$

- ➔ Speaker Classification Model does not need speaker labels as only embeddings are being extracted

III. Experimental Details

- ➔ Dataset: DAIC-WoZ [24]
  - ◆ 189 participants (Male and female)
  - ◆ 42 Depressed (Self-reported)
  - ◆ Audio and text.
- ➔ Input Features
  - ◆ Audio: Mel-spectrograms, Raw-Audio, ComparE16, Wav2Vec2 latent representation [30]
  - ◆ Text: Word2Vec [31]
- ➔ Models
  - ◆ DepAudioNet framework [25] : CNN+LSTM, ECAPA-TDNN [32], LSTM-only
- ➔ Evaluation Metrics
  - ◆ Depression detection: F1-Score (Majority Voting - MV)
  - ◆ Privacy -preservation: DeID Score [37]

De-Identification Score (DeID)

- ❖ Inspired by Voice-privacy literature [38].
- ❖ Evaluates speaker recognizability pre- and post-disentanglement.
- ❖ Scale: 0-100 (100 : Speakers fully unidentifiable post-disentanglement).

Code & Model ➔

IV. Results & Discussion

Baseline vs. ADV vs. USSD for 4 input features and 3 models.

Feature	Model	Disentanglement	Number of Parameters ↓	F1-AVG (MV) ↑	F1-ND ↑	F1-D ↑	*DeID* ↑
Mel-Spectrogram	CNN-LSTM	No	280k	0.658	0.756	0.560	NA
		ADV	293k	0.694	0.773	0.615	14.01%
		USSD	280k	0.683	0.783	0.583	10.29%
	ECAPA-TDNN	No	515k	0.709	0.809	0.609	NA
		ADV	529k	0.746	0.826	0.667	3.69%
		USSD	515k	0.746	0.826	0.667	5.97%
Raw-Audio	CNN-LSTM	No	445k	0.669	0.792	0.546	NA
		ADV	459k	0.709	0.809	0.609	55.83%
		USSD	445k	0.746^{+}	0.826	0.667	45.35%
	ECAPA-TDNN	No	595k	0.694	0.773	0.615	NA
		ADV	609k	**0.790**	0.880	**0.700**	22.32%
		USSD	595k	0.773^{+}	0.851	0.696	19.90%
ComparE16	LSTM-only	No	1.15M	0.694	0.773	0.615	NA
		ADV	1.18M	0.762^{+}	0.857	0.667	68.37%
		USSD	1.15M	0.776	**0.885**	0.667	**92.87%**
Wav2vec2	LSTM-only	No	3.6M	0.683	0.783	0.583	NA
		ADV	3.7M	0.747	0.863	0.632	52.43%
		USSD	3.6M	0.720	0.840	0.600	58.65%

- ➔ Speaker Disentanglement (ADV or USSD) >> Baseline
  - ◆ Avg. improvement in F1-Score - (8.3% for ADV and 8.2% for USSD)
- ➔ F1-USSD ≈ F1- ADV without speaker labels and additional parameters.
- ➔ DeID-USSD > DeID-ADV => USSD has the best speaker disentanglement.

- ➔ ADV
  - ◆ F1-Score: 0.790
  - ◆ DeID: 22.32%
- ➔ USSD
  - ◆ F1-Score: 0.776
  - ◆ DeID: 92.87%

Text-Fusion

Audio-Model	Audio-only	Word2Vec	Audio + Text Fusion	*DeID* (Audio-only)
Raw-Audio ECAPA-TDNN (ADV)	0.790	0.762	0.860	22.32%
ComparE16 LSTM-only (USSD)	0.776	0.762	0.830	92.87%

- ➔ F1 Score: USSD + Text > USSD.
- ➔ Text and USSD may be complimentary.