Design and Development of sEMG-based Silent Speech Recognition

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Background

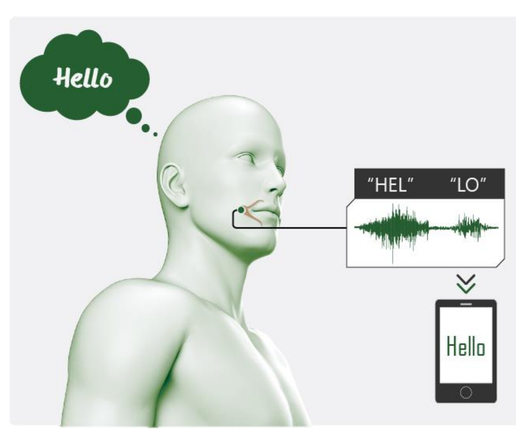
Speech provides an attractive modality for human-machine interface (HMI) through automatic speech recognition (ASR). But ASR suffers from three primary limitations:

1) Performance degradation in presence of ambient noise
2) Limited ability for privacy/secrecy
3) Poor accessibility for those with speech disorders.

These limitations have motivated the need for alternative non-acoustic modalities of subvocal or silent speech recognition (SSR).

Objective

We set out to design and develop a SSR system based on recordings of the surface electromyographic (sEMG) signal from articulator muscles of the face and neck during silently mouthed (subvocal) speech.



Methods

1) Experiment Setup

- **Subjects –** n=18 healthy (11 males, 8 females, age range 18-42 y.o.)
- **sEMG Sensors**: 8 DE 2.1 sensors and Trigno™ Mini sensors (Delsys, Natick, USA)
- **Protocol** – Subjects silently mouthed words while sEMG activity was recorded from muscles of face and neck.

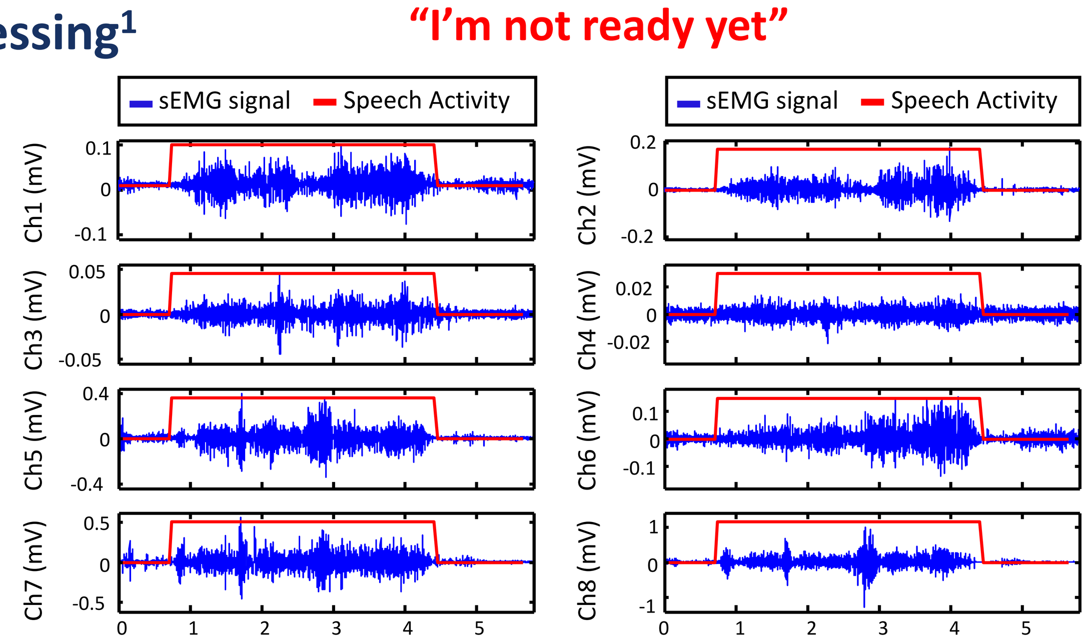
2) Data Collection

Data Corpus	Subjects	Vocabulary/Phrases
Isolated Words	Controls (n=9)	65 words and digits
Sequences of Words	Controls (n=4)	202 words, 1,200 sequences
Continuous Speech	Controls (n=5)	2,200 words, 1,200 phrases

3) Initial Data Processing[1]

- Separating speech from non-speech sEMG activity
- Finite multi-channel state machine
- Robust against noise

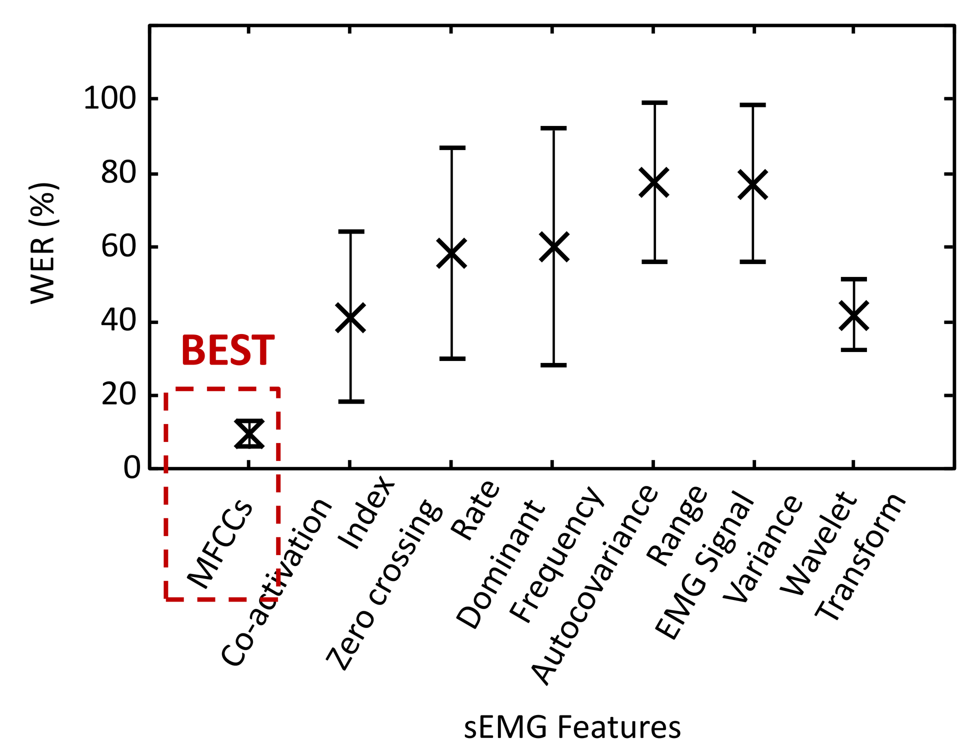
"I'm not ready yet"



Algorithm Development – Strategic evolution of Hidden Markov Models (HMMs) for SSR

Challenge 1

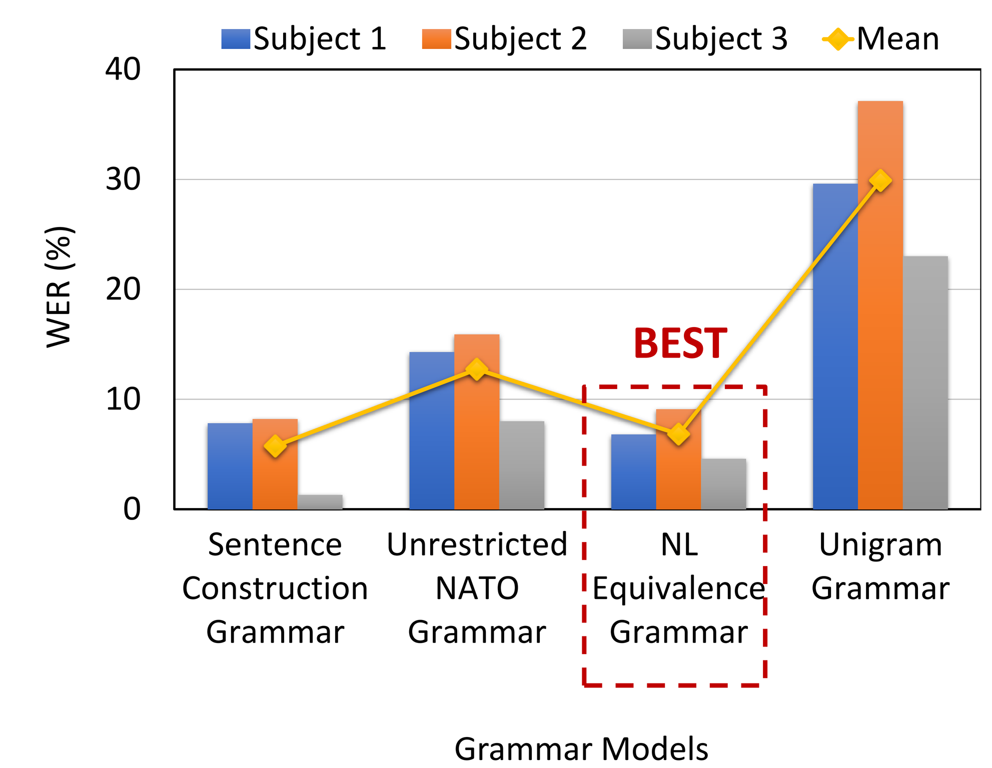
Discriminating isolated words using sEMG-based speech related features



- Mel Frequency Cepstral Coefficients (MFCCs) provided the lowest word error rate (WER) of 9.6% across of all combinations of features tested.

Challenge 2

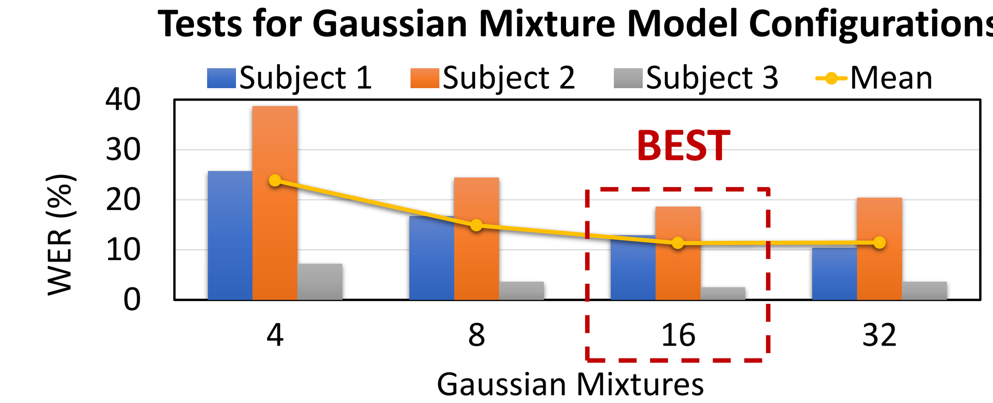
Tracking sequences of words from patterns of sEMG signals using grammatical context



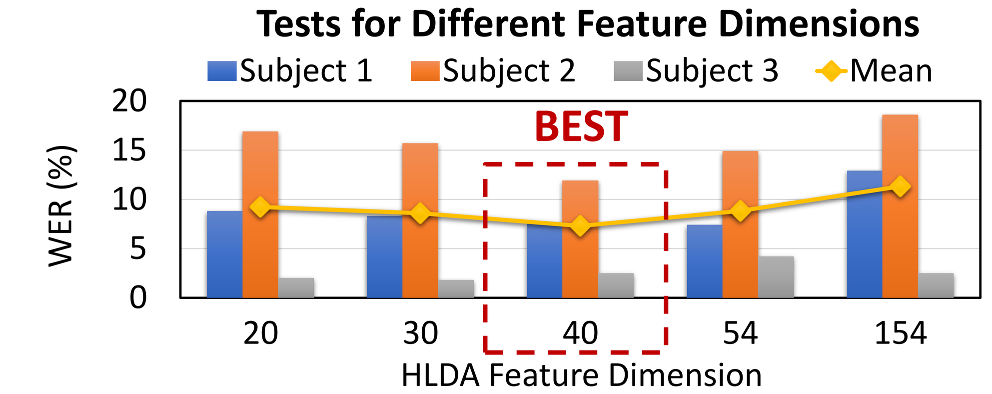
- Natural Language (NL) Equivalence Grammar provided a larger range of linguistically correct English sentences and had the second lowest WER of 6.8%.

Challenge 3

Recognizing a large vocabulary of untrained words using phoneme-based models



- Increasing to 16 Gaussian mixtures to model each HMM state decreased WER to 11.3%



- Reducing the HLDA feature dimension to 40 decreased the WER to 7.3%

Final sEMG SSR System – Algorithms, Sensors and Mobile Deployment

SSR Configuration:

- *Sensors* – sEMG 4 sensor-array (under development) worn on face and neck
- *Features* – MFCCs
- *Grammar* – NL Equivalence
- *Recognition Toolkit* – KALDI
- *Model* – HMM Triphone, HLDA Feature Reduction, maximum likelihood linear regressions (MLLR), subspace Gaussian mixture modelling (SGMM)

SSR Sensors: Trigno™ Quattro Facial Array

- Wireless/Bluetooth communication for mobile use

SSR System Performance (WER):

Subject	Digits	Text Messages	Special Operations	Common Phrases	Mean WER
1	2.7	0.9	2.0	0.0	1.4
2	15.4	15.9	8.0	15.4	13.9
3	20.7	12.1	13.6	5.2	12.9
4	18.2	10.3	10.6	3.7	10.7
5	12.2	5.6	3.4	1.2	5.6
Mean	13.8	9.0	7.5	5.1	**8.9**
SD.	7.0	5.8	4.9	6.1	**5.3**

FINAL

Conclusion

- Our SSR system was able to recognize subvocal speech with 8.9% WER from a 2,200-word vocabulary of 1,200 continuous phrases including previously unseen words.
- The miniaturized sensors provide a robust and unencumbering facial interface that can transmit data via custom wireless or Bluetooth protocol for portable integration with a mobile device.
- These results demonstrate the viability of our SSR system as a silent modality of speech communication that can be developed further for persons with speech impairments (Meltzner et al, 2017), military personnel, or consumer applications.

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References

1. Meltzner et. al. Silent Speech Recognition as an Alternative Communication Device for Persons With Laryngectomy. IEEE Trans. on ASLP, 2017.