IPSN 2021
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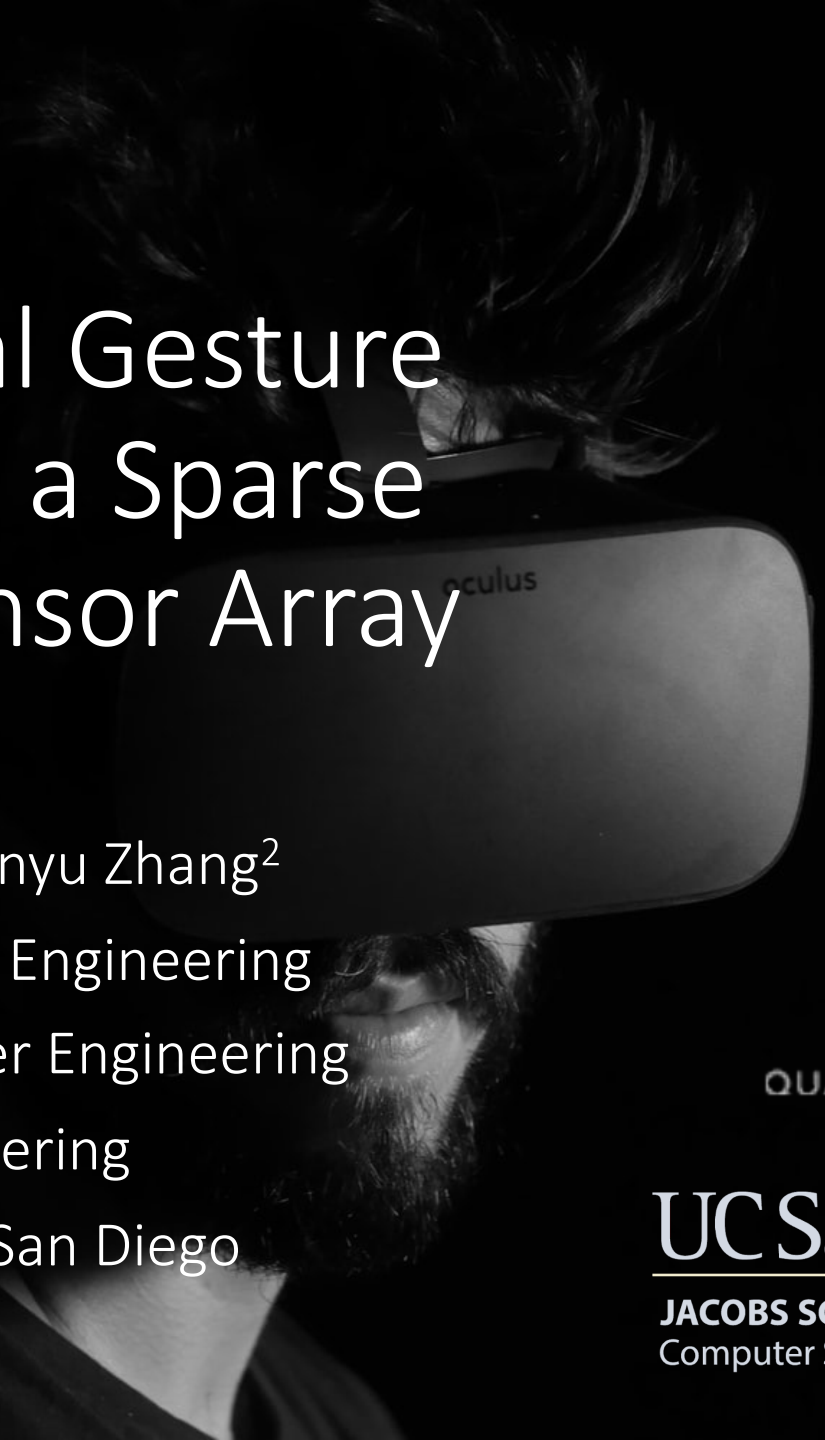
NASHVILLE, TENNESSEE, USA

ExGSense
Toward Facial Gesture Sensing with a Sparse Near-Eye Sensor Array



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QUALCOMM INSTITUTE
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UC San Diego
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Electrical and Computer Engineering

Collaborations Through VR

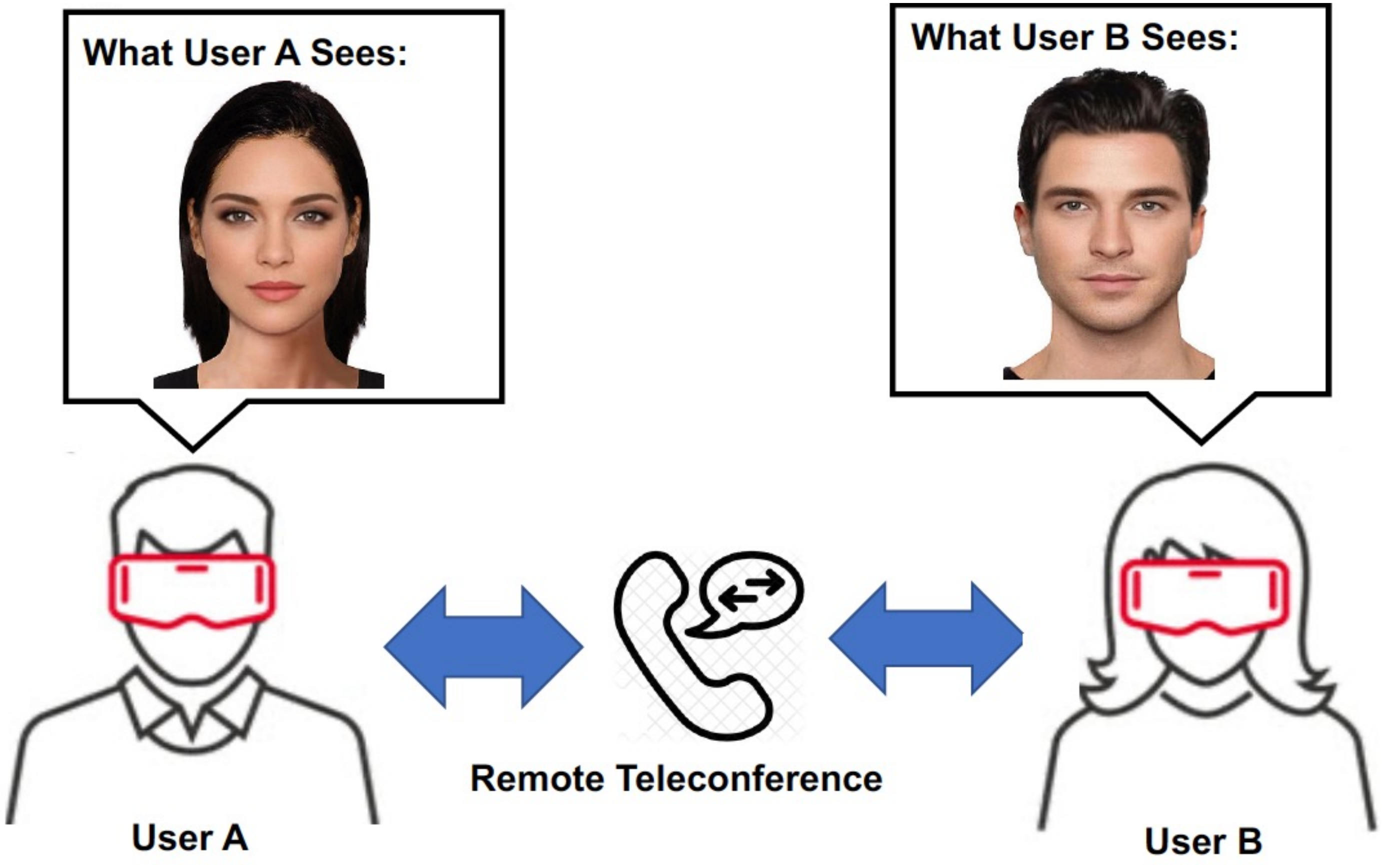
- Enables a new forms of telepresence applications;
- Empowers professionals to virtually connect with one to another;

Immersive Data Analysis,
(Rabaudo et. al., '20)

Training for Components Assembling
(Rumii software)

Sense of Co-Presence is the Key!

- Capturing full face of remote collaborators enables one to perceive the non-verbal cures of the remote collaborators, yet challenging!



Existing Solutions

- Camera Based Solution (Inside or Outside of HMD);
  - Occlusions;
  - $$

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- Camera Based Solution (Inside or Outside of HMD);
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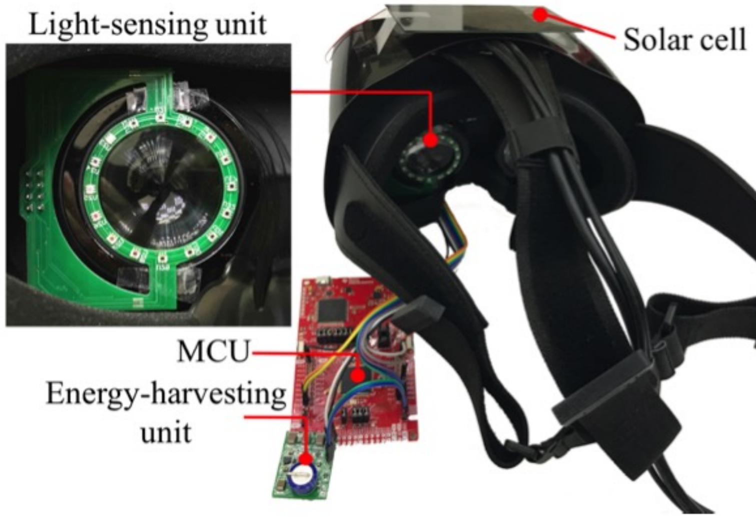
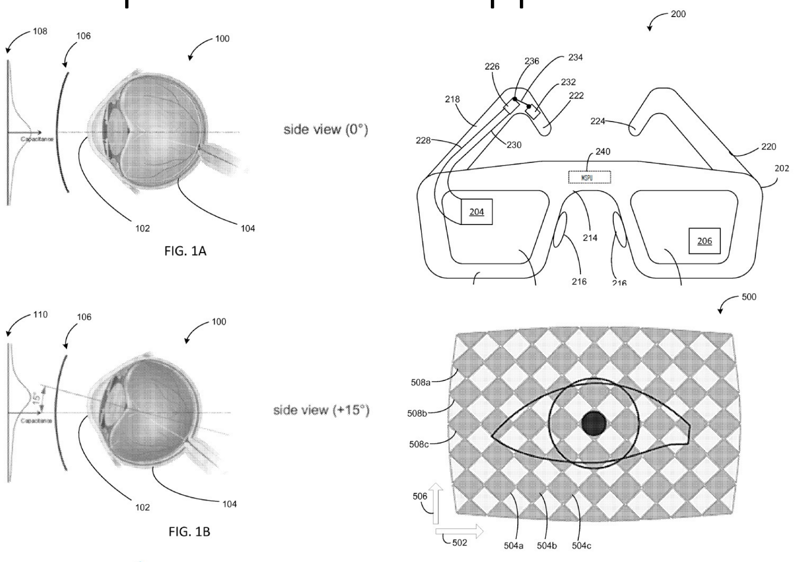
- Proximity & Pressure Based Solution;
  - Complicated hardware design;
  - Can only detect partial facial gestures;

IR Based Approach



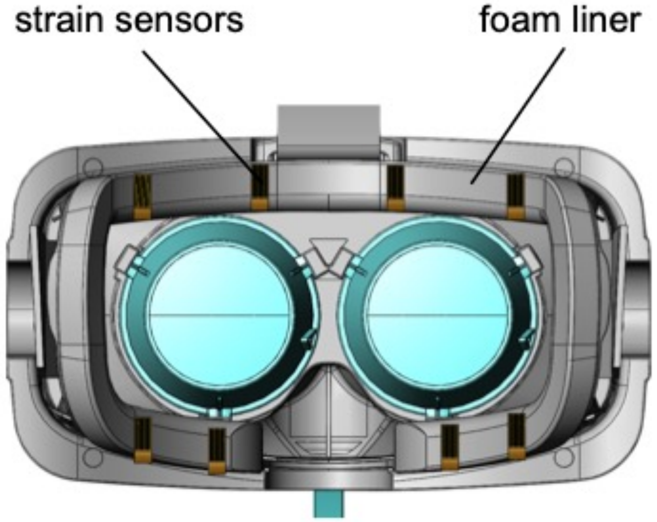
(LiGaze, Li *et. al.* ‘17)

Capacitive Based Approach



(Bergman *et. al.*, ‘15)

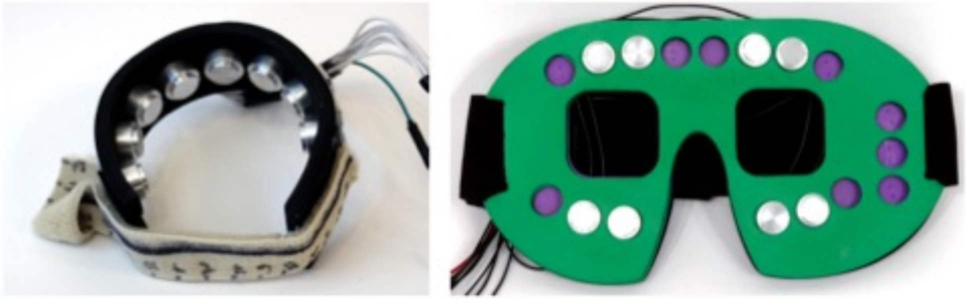
Strain Based Approach



(Li *et. al.*, ‘15)

Existing Solutions

- Camera Based Solution (Inside or Outside of HMD);
  - Occlusions;
  - $$
- Proximity & Pressure Based Solution;
  - Complicated hardware design;
  - Can only detect partial facial gestures;
- Interferometry and Tomography Based Solution;
  - Low sensing granularity;
  - Impacts from differences of underlying anatomical patterns across different users;



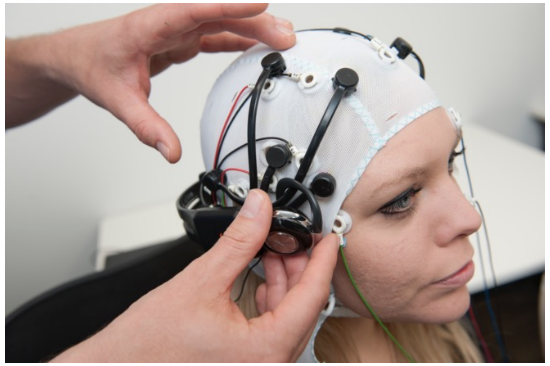
(Interferi, Iravantchi *et. al.*, CHI '19)

Existing Solutions

- Biosignal Based Solution;
  - Eye activities detections using EOG;
  - Facial muscle related gestures detections using EMG;
  - Coarse grained emotion detections, bulky as well as complicated setup using EEG;

(J!NE Related, Ishimaru *et. al.*, UbiComp ’14, Rostaminia *et. al.* ETRA ’19, IMWUT ‘19)

(AlterEgo, Kapur *et. al.*, IUI ‘18)



(Emotiv EPOC ‘18)

ExGSense

- **Sensing Modality:** We used the near-eye biopotential sensors to detect full face expressions. To achieve this, we explore the paradigm of *indirect* sensing where the lower facial gestures can be detected by the transducers resting on the upper face;

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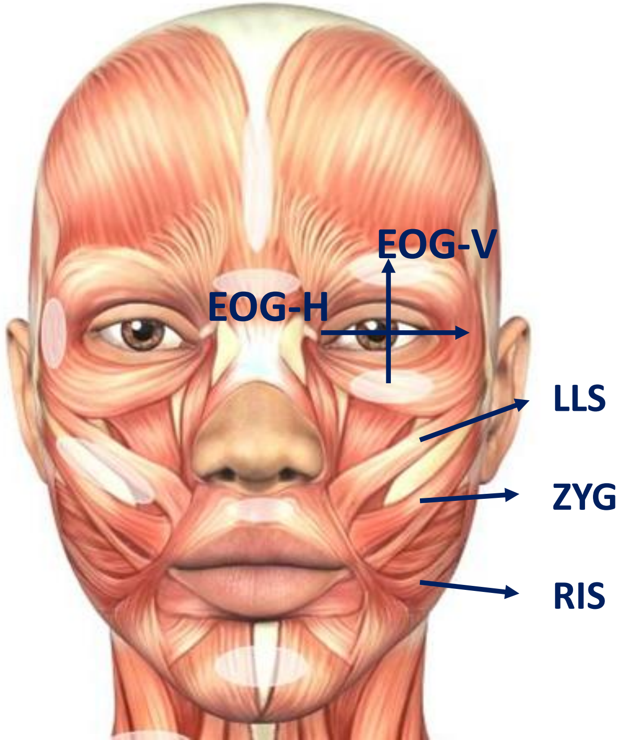
- Detection Framework: We propose a dual-branch multiview representation learning pipeline, which can explicitly exploit the sensor diversities across time-frequency-spatial domains. We further propose a simple re-calibration approach for adapting the pretrained model for different users;
- Prototype & Evaluations: We build a proof-of-concept prototype of ExGSense and conduct the user study to verify its ability to concurrently track the fine-grained upper face eye and lower face mouth gestures by fully leveraging the underlying facial anatomy patterns;

Preliminary

ElectroOculoGraphy (EOG)

- ~μV;
- Induced by eye movements;
- Can be decomposed to EOG-H and EOG-V;



Preliminary

ElectroOculoGraphy (EOG)

- ~μV;
- Induced by eye movements;
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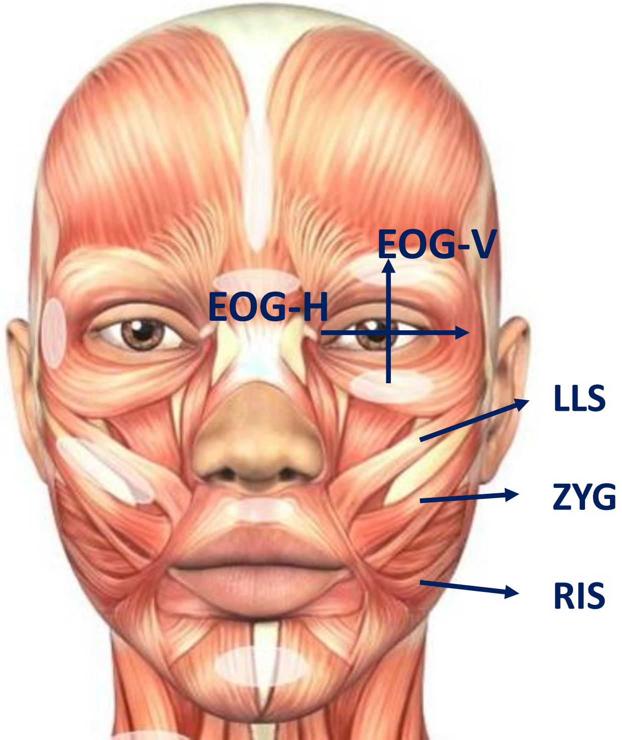
ElectroMyoGram (EMG)

- ~mV;
- Induced by muscle contract and relax;
- Indirect Sensing: using transducers resting on the upper face to detect the lower face mouth gestures;
- 3 Muscle Groups:
  - Levator Labii Superioris (LLS);
  - Zygomatics Majors (ZYG);
  - Risorius (RIS);

2 Unwanted Noise:

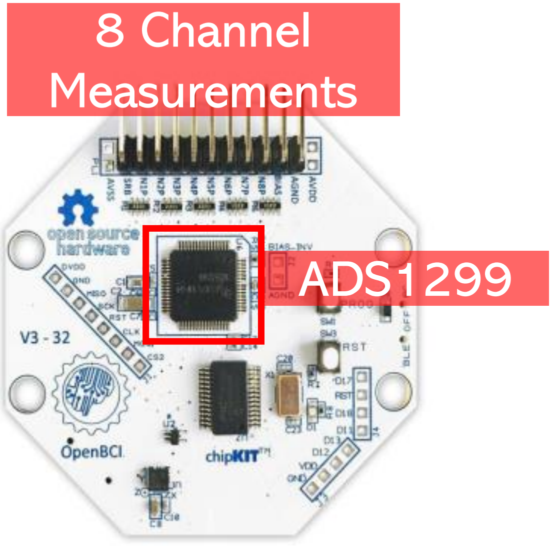
- Inter-Person Variations;
- Inter-Session Variations;



Implementations

Data Acquisitions:

- OpenBCI Cyton Board;
- 8 16-bit ADC (TI ADS1299);
- X24 Gain;
- Stream data to host PC through BLE 4.0;
- Sampling Frequency f_s= 250Hz;



OpenBCI Cyton Bioprocessing Board

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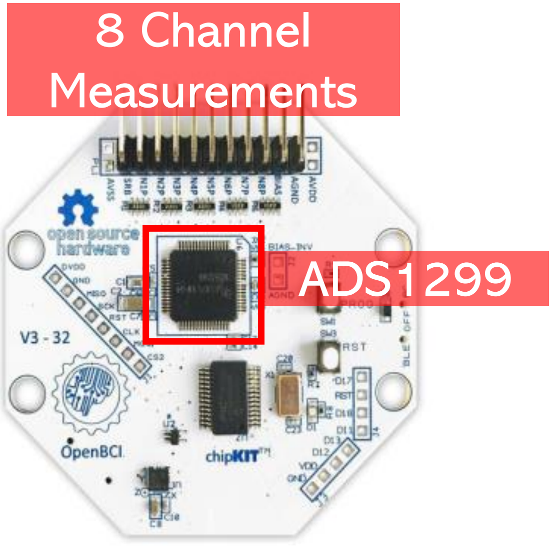
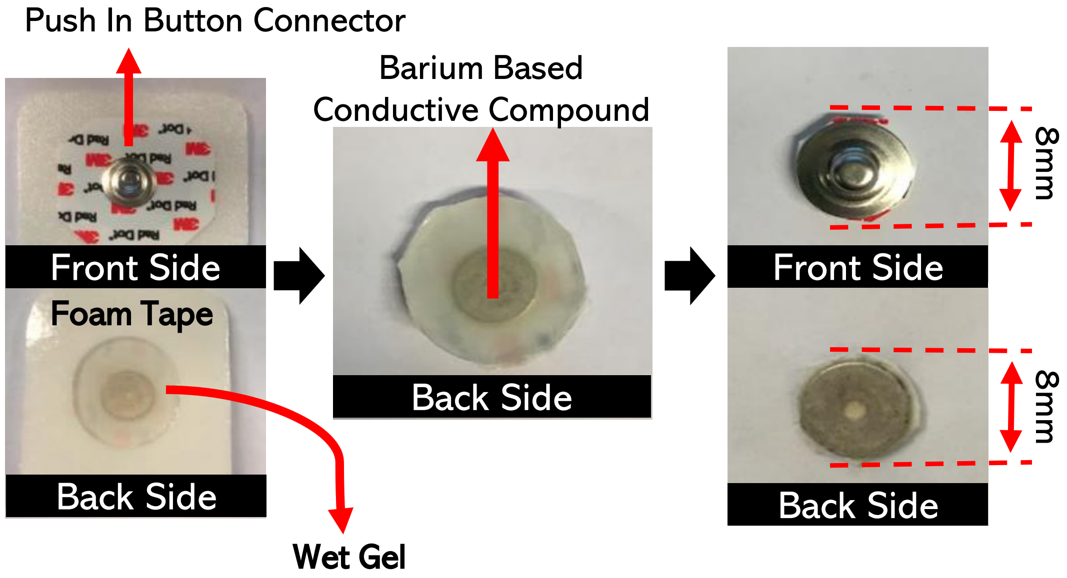


OpenBCI Cyton Bioprocessing Board

Transducer:

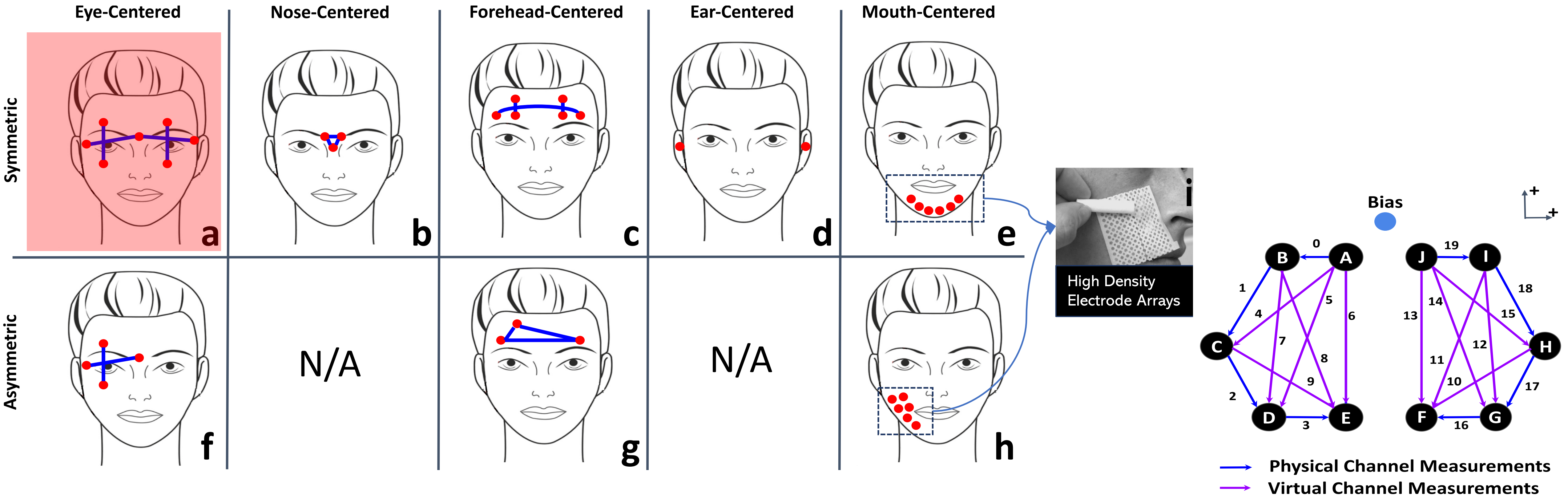
- Disposal wet electrodes can reduce noise, yet are less comfortable and impractical for mobile applications;
- Remove the wet gels to enable the comfortable reusable electrodes with reasonable signal quality degradations;



Transducer Arrangement

Indirect Sensing & Symmetric Design

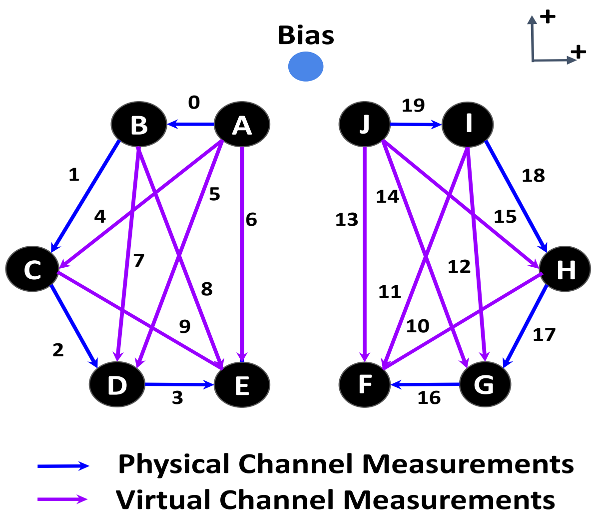
- Indirect Sensing: detect the lower facial gestures by only leveraging the transducers resting on the upper face;
- Symmetricity: introduce spatial redundancies and minimize imperfect sensing performance;



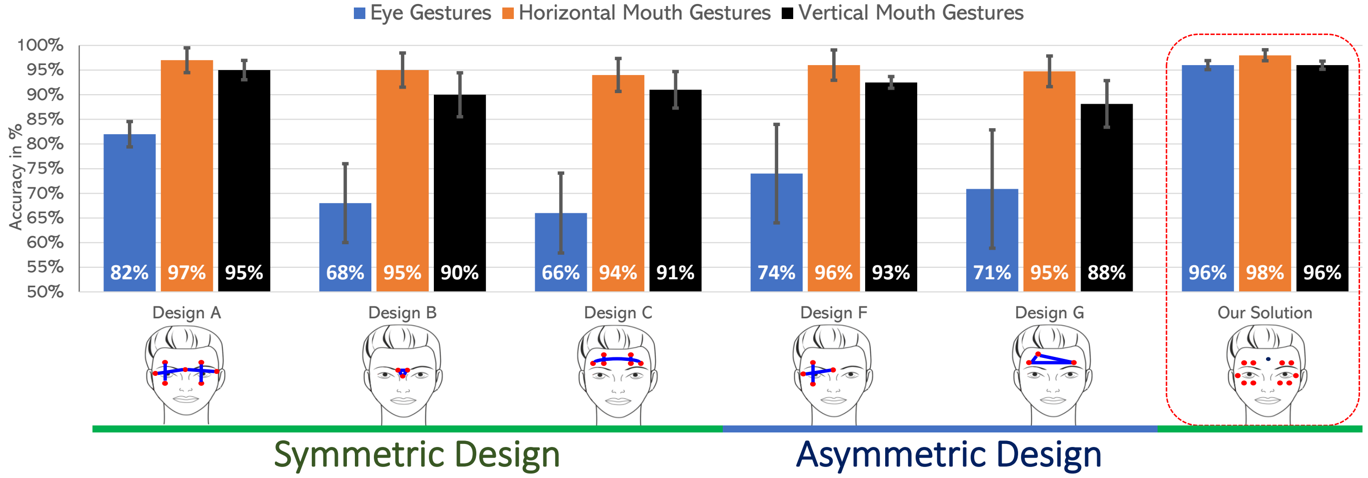
Transducer Arrangement

Virtual Channel Measurements

- Physical Channel Measurements (Blue): Direct collected by DAQ;
- Virtual Channel Measurements (Pink): Computed algorithmically;

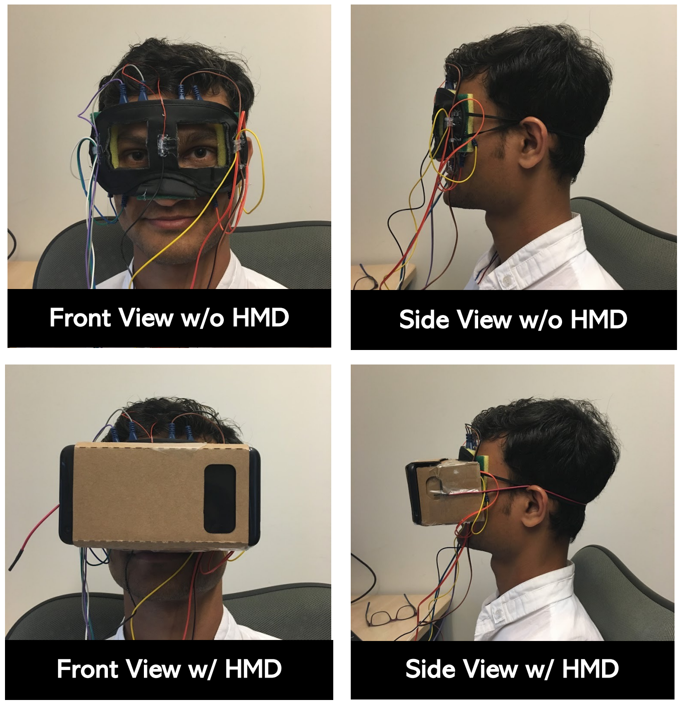


Micro Benchmark



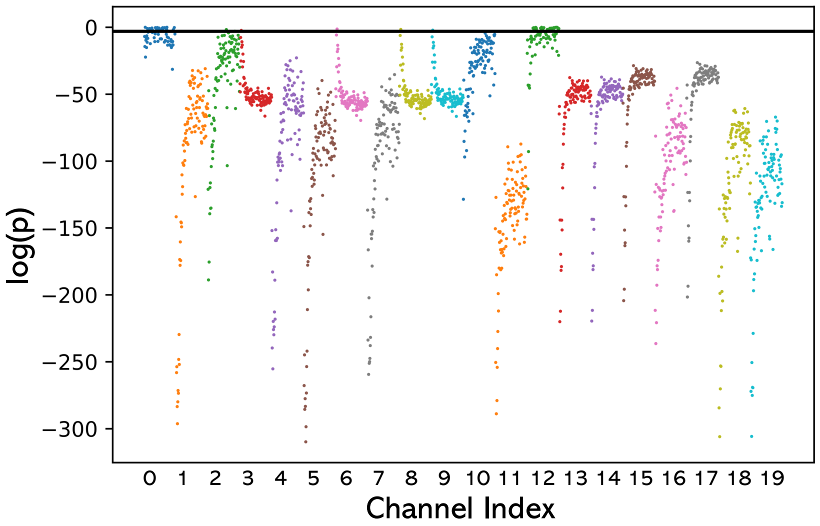
- 4 Participants;
- Eye Gestures: None, Blink, Gaze Up/Down/Left/Right;
- Horizontal Mouth Gestures: Small, Medium, Large;
- Vertical Mouth Gestures: Small Medium, Large;

Prototype

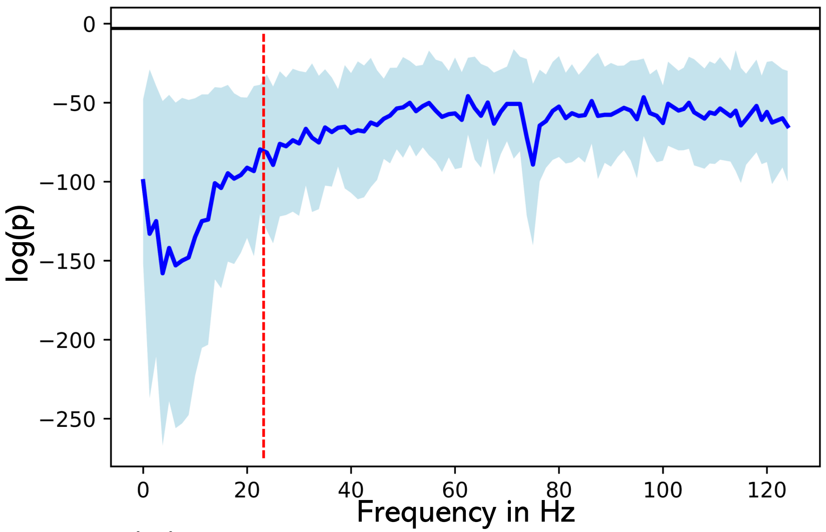


Algorithms – Finding Cut-Off Frequencies

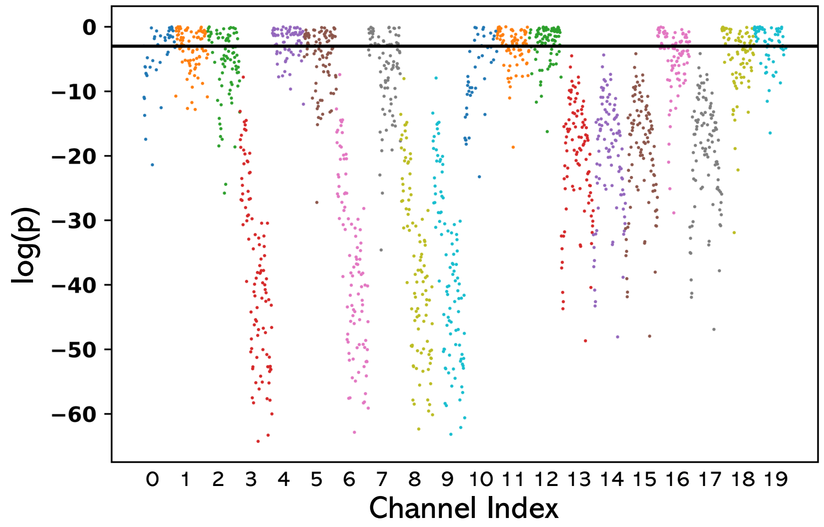
- Goal: Find optimal frequency that separates EMG & EOG;
- Only use FFT to perform the feature significance test;
- (a – b) p-value corresponding to each FFT bin at each channel;
- (c - d) p-value corresponding to each frequency, averaged across all channels;
- ~25Hz;



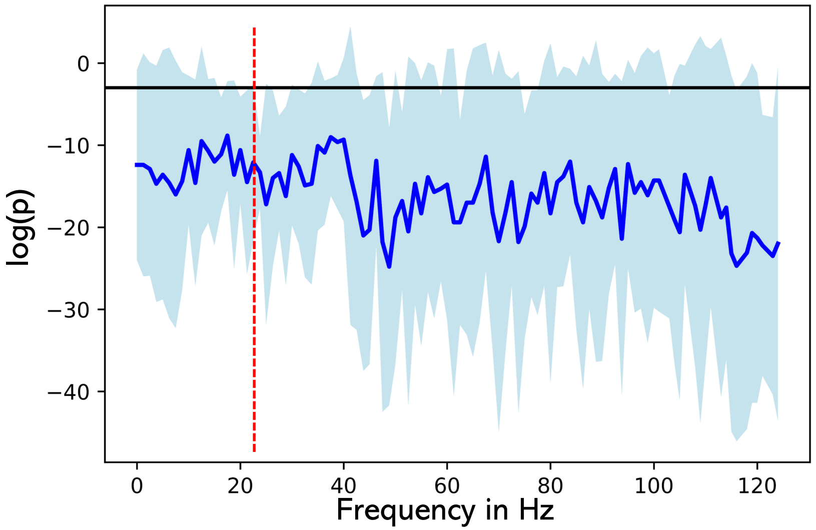
(a) Raw eye gesture results



(c) Avg. mouth gesture results



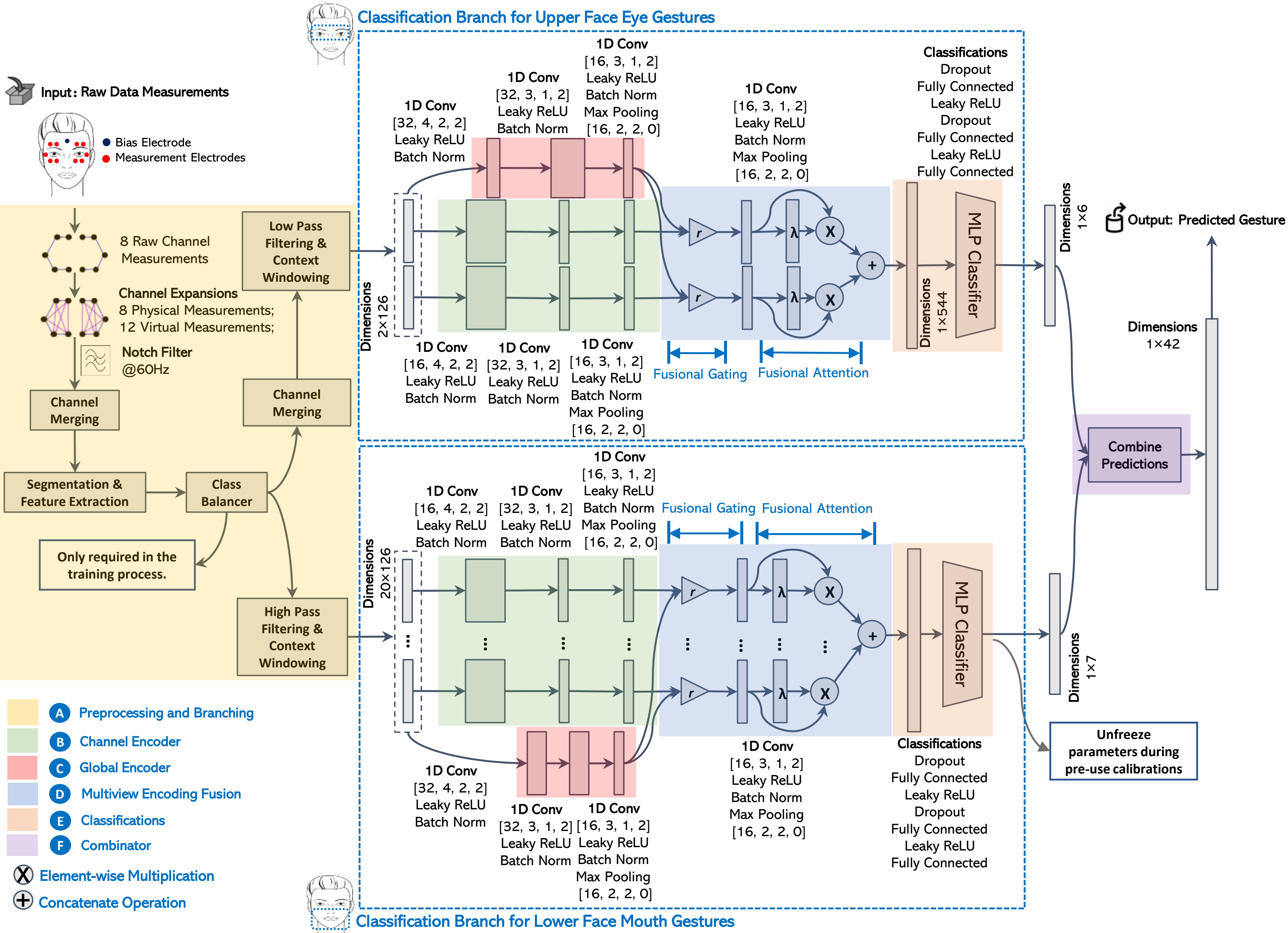
(b) Raw mouth gesture results



(d) Avg. mouth gesture results

Algorithms – Dual Branch Multi-View Classifications

- Channel & Global Encoders;
- Cross-Entropy Losses;
- Only the classification branch will be un-freezed for calibration purpose;
- PyTorch based implementation;



Sensing Events

- Emotion sensing and gesture detections are different;
- A Combinations of:

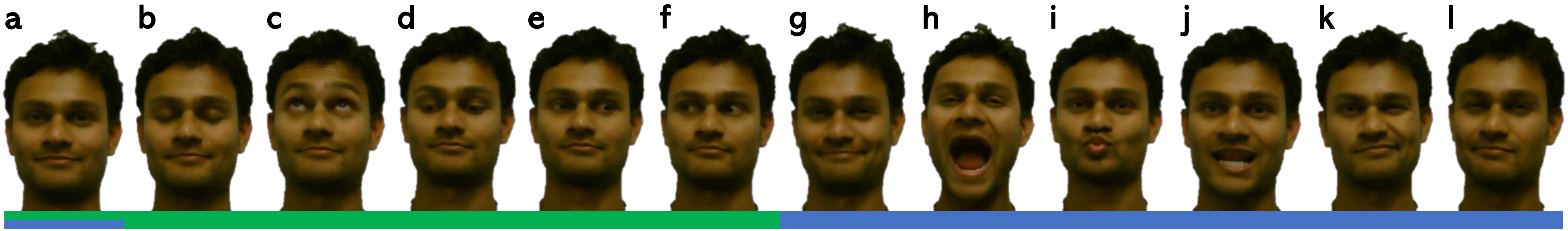
6 Eye Gestures [Green]:

- Neutral;
- Blinks;
- Gaze Looking Up;
- Gaze Looking Down;
- Gazing Looking Left;
- Gaze Looking Right;

7 Mouth Gestures [Blue]:

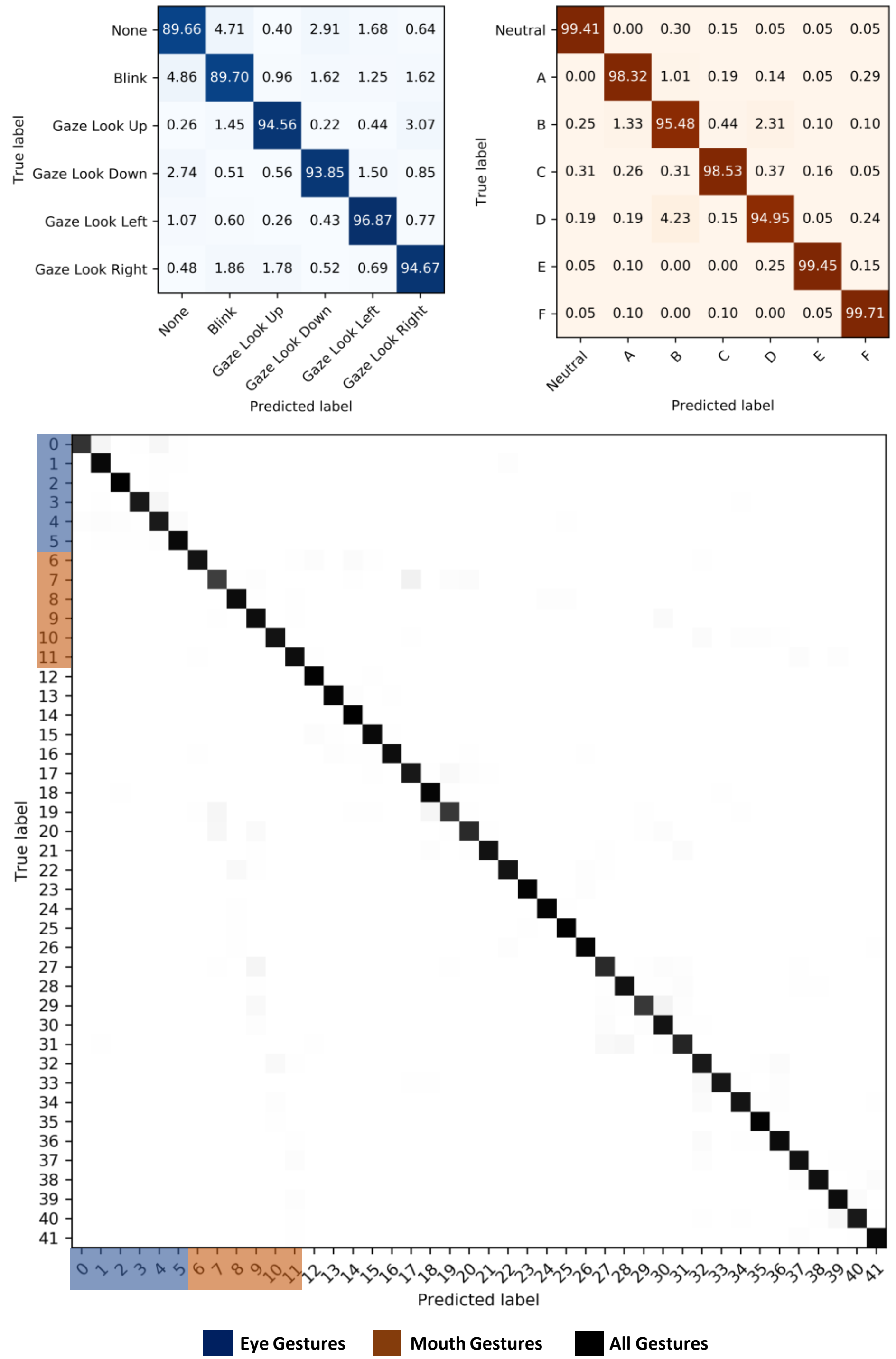
- Neutral;
- [A] Smile;
- [B] Mouth Open;
- [C]Kissy Mouth;
- [D] Tongue Touch Upper Teeth;
- [E] Raising Left Cheek;
- [F] Raising Right Cheek;

Index	Eye	Mouth	Index	Eye	Mouth
0	None	None	21	Gaze Right	B
1	Blink	None	22	Blink	C
2	Gaze Up	None	23	Gaze Up	C
3	Gaze Down	None	24	Gaze Down	C
4	Gaze Left	None	25	Gaze Left	C
5	Gaze Right	None	26	Gaze Right	C
6	None	A	27	Blink	D
7	None	B	28	Gaze Up	D
8	None	C	29	Gaze Down	D
9	None	D	30	Gaze Left	D
10	None	E	31	Gaze Right	D
11	None	F	32	Blink	E
12	Blink	A	33	Gaze Up	E
13	Gaze Up	A	34	Gaze Down	E
14	Gaze Down	A	35	Gaze Left	E
15	Gaze Left	A	36	Gaze Right	E
16	Gaze Right	A	37	Blink	F
17	Blink	B	38	Gaze Up	F
18	Gaze Up	B	39	Gaze Down	F
19	Gaze Down	B	40	Gaze Left	F
20	Gaze Left	B	41	Gaze Right	F



Single User Evaluations

- 10 participants;
- Train and test on the single user;
- The data of non-mixture gesture of each user is split into 70%, 10% and 20% for training, validation and testing;
- The model is train by 6 + 7 = 13 gestures;
- F1 score is used for balancing between precision and recall;



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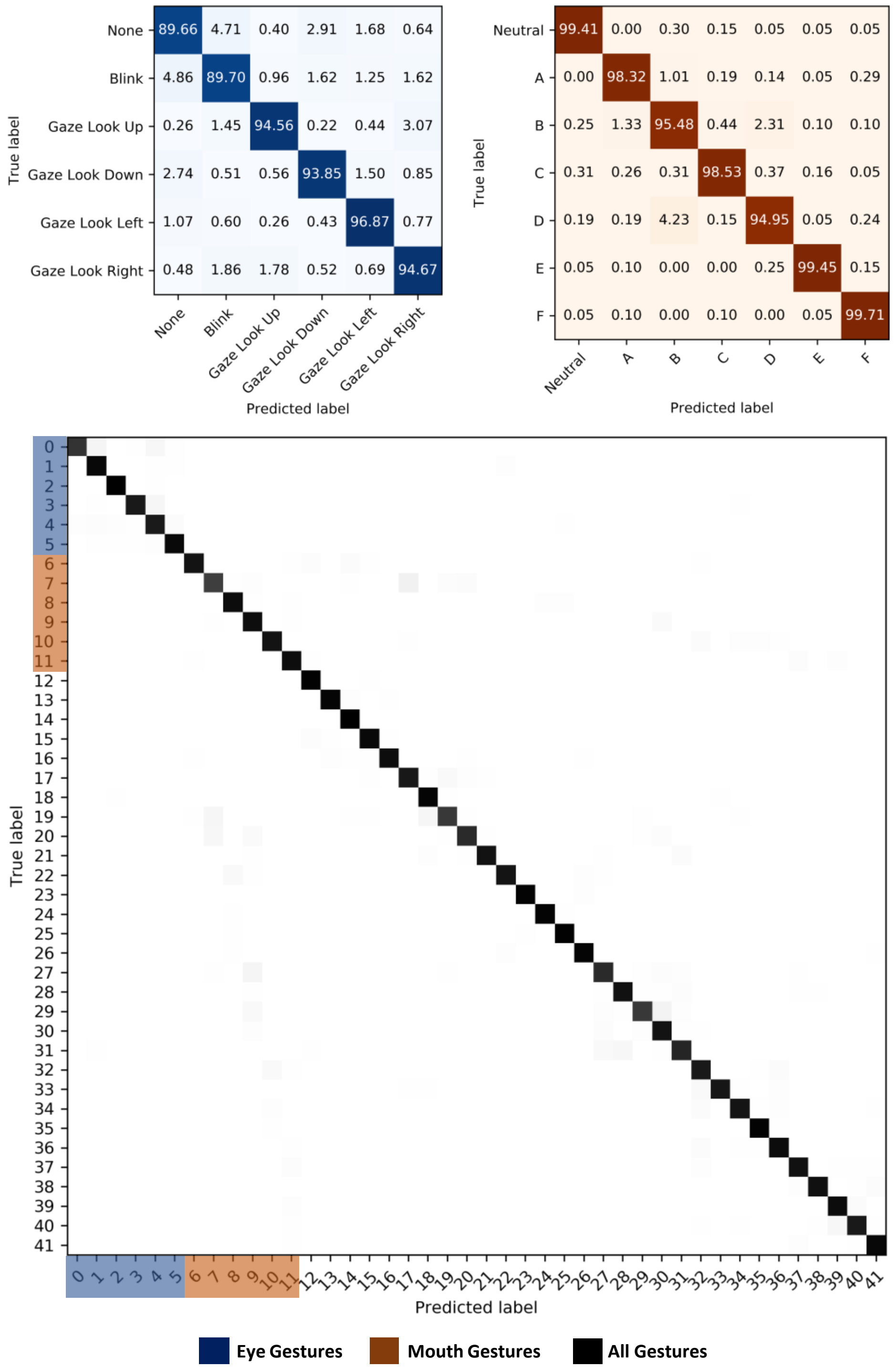
- The model is train by 6 + 7 = 13 gestures;
- F1 score is used for balancing between precision and recall;
- Findings:
  - Overall ~93% accuracy;
  - Competitiveness of dual-branch classification pipeline (reduce # of training examples from 6 X 7 = 42 to 6 + 7 = 13);
  - Sensitivity of mouth gesture detections when mixed with eye gestures (~98%);



User Independent Evaluations without Partial Calibrations

- Understand how ExGSense can be adapted to an "unseen" participants;

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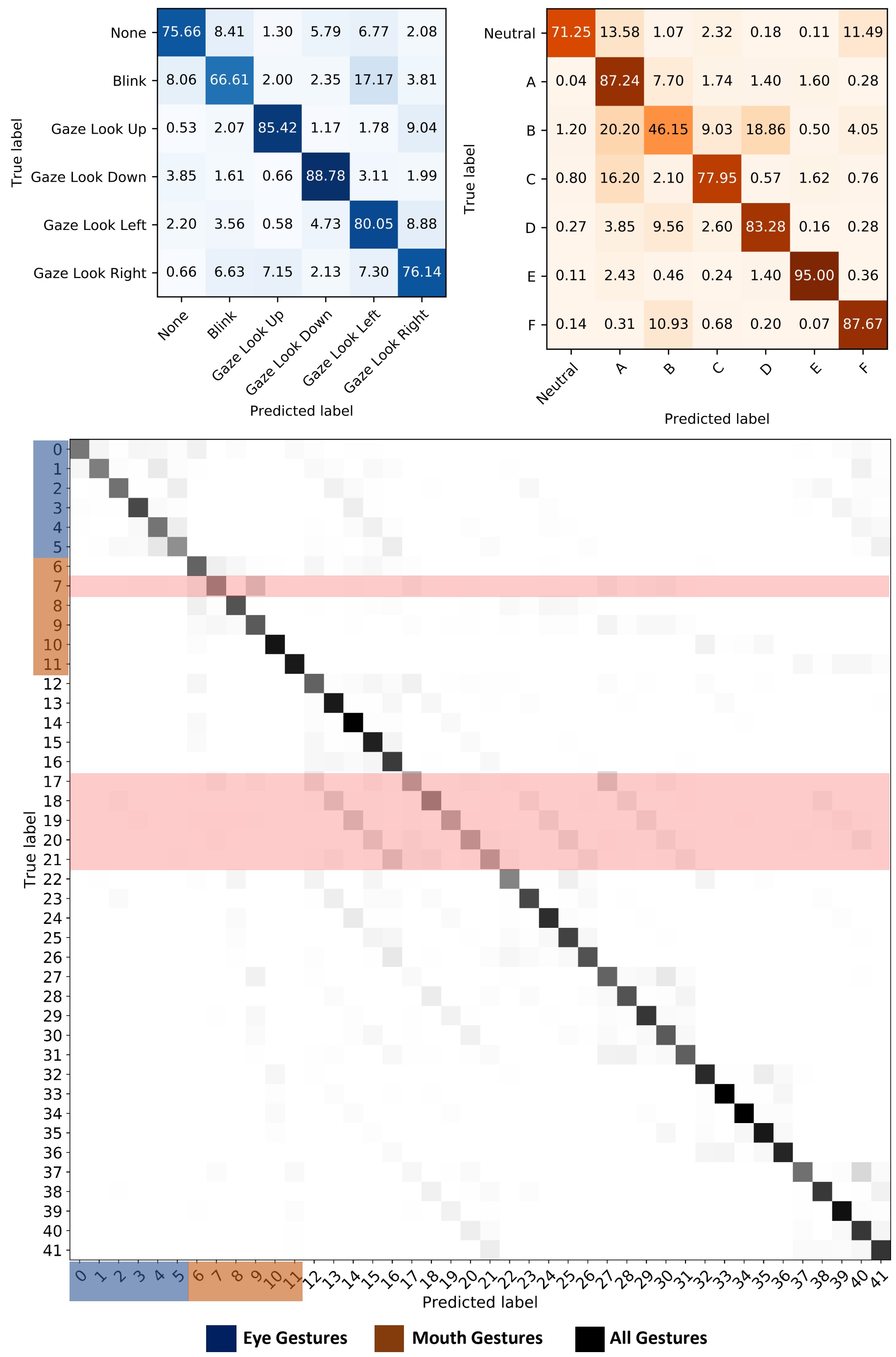
- Leave one user out cross validation;

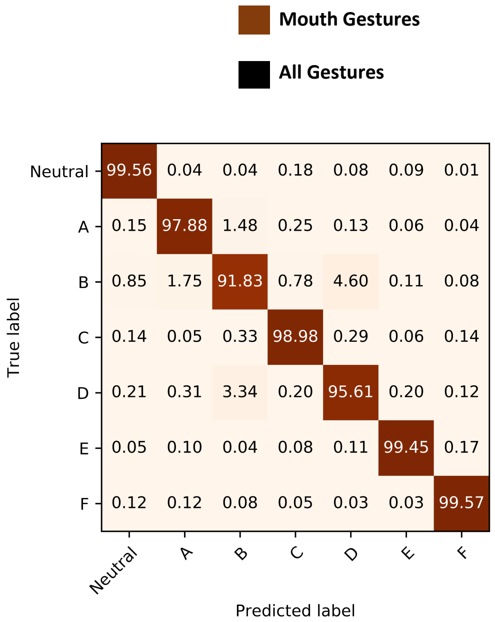
User Independent Evaluations <u>without</u> Partial Calibrations

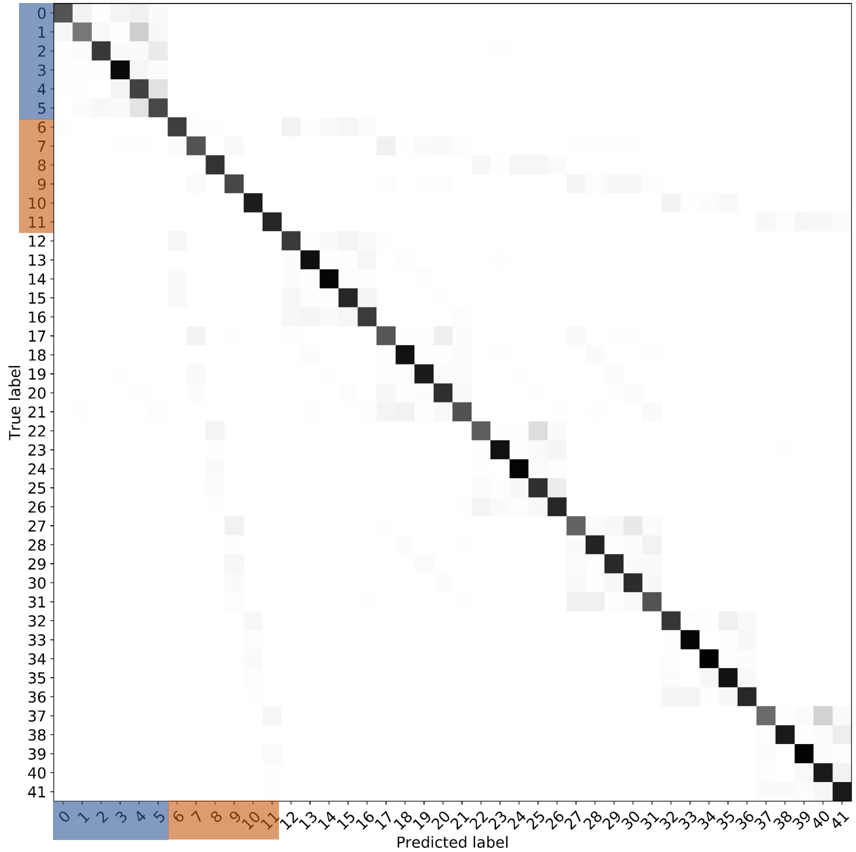
- Understand how ExGSense can be adapted to an “unseen” participants;
- Leave one user out cross validation;
- ~80% for eye and ~78% for mouth;
- Low performance for mouth gesture B (mouth open);

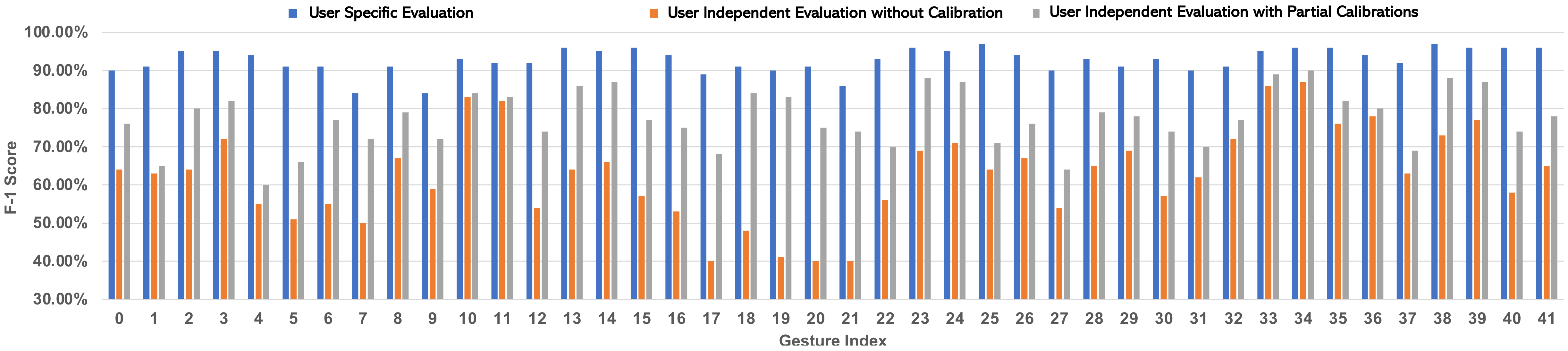


User Independent Evaluations with Partial Calibrations

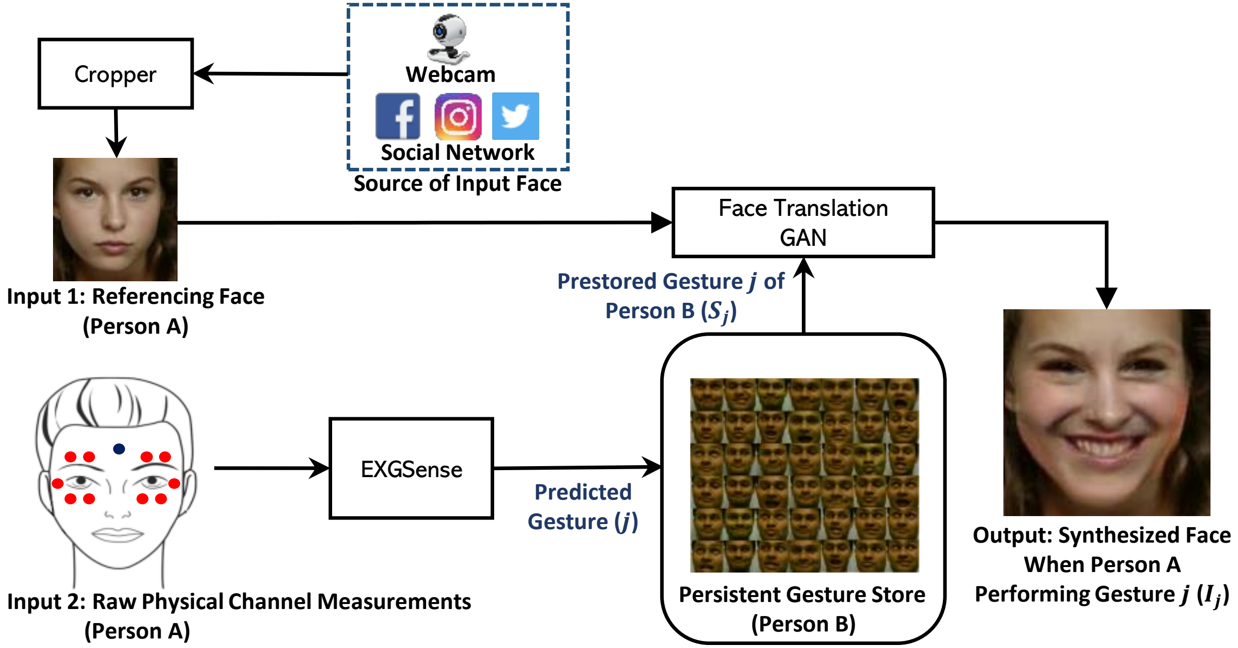
- A new user is asked to provide ~2min data for 6 non-mixture mouth gestures (exclude the none class);
- An overall accuracy of ~77%;

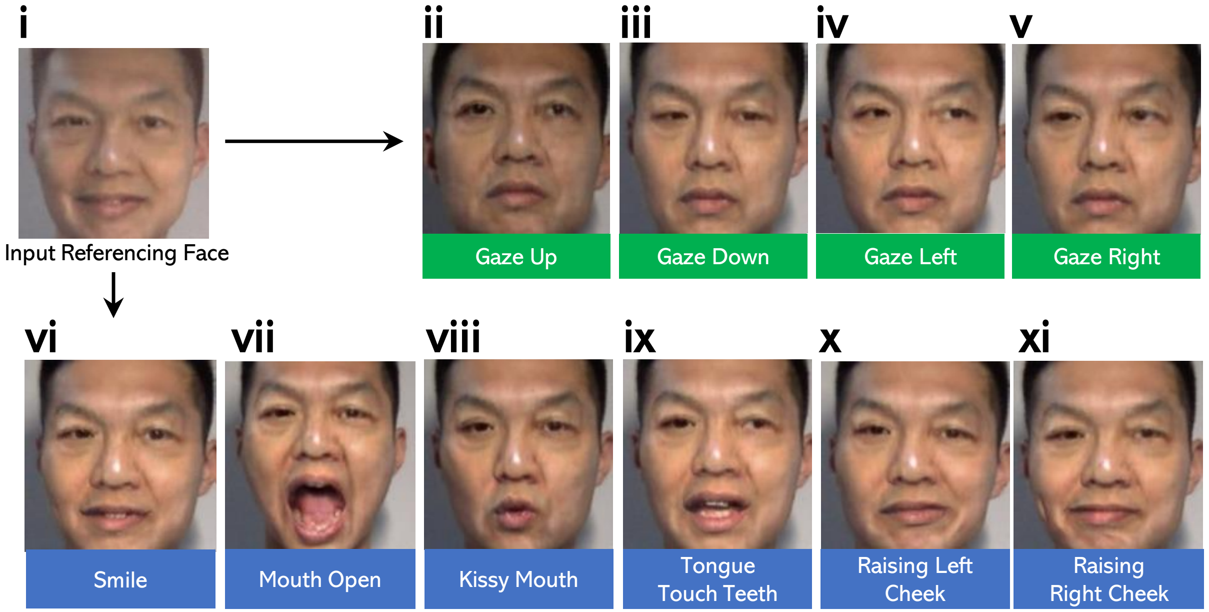






Examples


Cropper
Webcam
Social Network
Source of Input Face
Face Translation GAN
Input 1: Referencing Face (Person A)
Prestored Gesture j of Person B (S_j)
EXGSense
Predicted Gesture (j)
Persistent Gesture Store (Person B)
Output: Synthesized Face When Person A Performing Gesture j (I_j)
Input 2: Raw Physical Channel Measurements (Person A)


i
Input Referencing Face
ii
Gaze Up
iii
Gaze Down
iv
Gaze Left
v
Gaze Right
vi
Smile
vii
Mouth Open
viii
Kissy Mouth
ix
Tongue Touch Teeth
x
Raising Left Cheek
xi
Raising Right Cheek

Limitations & Future Work

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- Continuous efforts on addressing multi-facet issues related to usability and incorporations into commercially available VR headset;

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- Real-time and continuous facial tracking and reconstructions;
- While transferring to new users, a small set of training samples are still required for model calibration purpose;
- Continuous efforts on addressing multi-facet issues related to usability and incorporations into commercially available VR headset;
- A more diverse of participants;

Thank You!

Hope you enjoy our work!

For more detail, please refer to our manuscripts!

Contact: chenchen@ucsd.edu