# UBAS: An Ultrasound Based Air-writing System

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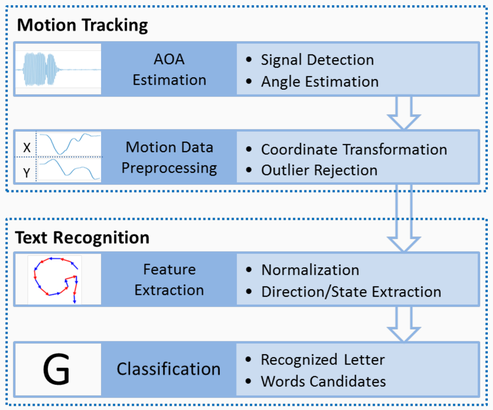
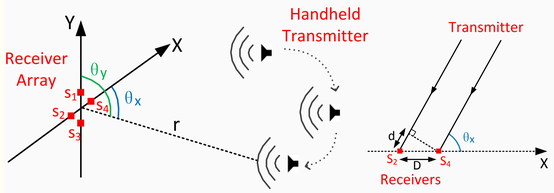
## 1. Introduction

- Gestures play an essential role in both human-human and human-machine interaction
- Ultrasound provides high accuracy in localization and tracking
- We propose an accurate and low cost ultrasound-based text recognition system

## 2. System Structure




## 3. Motion Tracking




For a certain angle, the noise-free phase difference vector:

$$\phi_i(\theta_x) = \frac{2\pi d}{\lambda_i} = \frac{2\pi f_i \sin(\theta_x) D}{v} \quad (i = 1, ..., N), \quad (1)$$

- $f_i$ is the $i^{th}$ frequency component of the signal.
- $v$ is the speed of signal propagation.

The observed phase-difference:

$$\hat{\psi}_i = \text{ang}(Y_1(f_i) \cdot Y_2^*(f_i)) = \hat{\phi}_i - 2\pi N_i, \quad (2)$$

- $Y_1$ and $Y_2$ are the DFT (Discrete Fourier Transform) of the received signals at sensor $S_1$ and sensor $S_2$, respectively.

Phase mismatch function:

$$e(\theta_m) = \sum_{i=1}^{N} |\hat{\psi}_i - \psi_i(\theta_m)| = \sum_{i=1}^{N} |\hat{\psi}_i - \text{wrap}(\phi_i(\theta_m))|, \quad (3)$$

$$\text{wrap}(\alpha) = \left(\frac{\alpha}{2\pi} - \left\lfloor \frac{\alpha}{2\pi} \right\rceil\right) \cdot 2\pi, \quad (4)$$

- $\theta_m$ is the angle candidates.

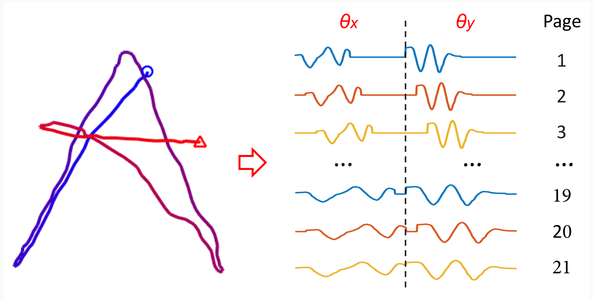
Search based AOA estimation:

$$\hat{\theta} = \arg \min_{\theta_m} \{e(\theta_m)\}. \quad (5)$$

## 4. Letter Recognition

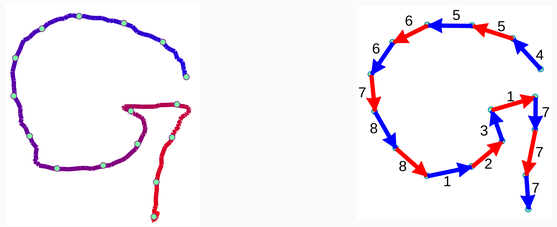
**Letter Angle-based Model**: The template letters can be represented by an $2K$ matrix $D_t$ where $M$ is the number of letters, $K$ is the length of the angles vector. We extend the original template matrix to $D_r$ based on shift and shrink. Classification can be done by matrix multiplication:

$$V = D_r^T g \quad (6)$$




Dynamic time warping (DTW), redundant dictionary (RD), RD with decision tree (RD-DT) and neural network (NN) will utilize this model for classification.

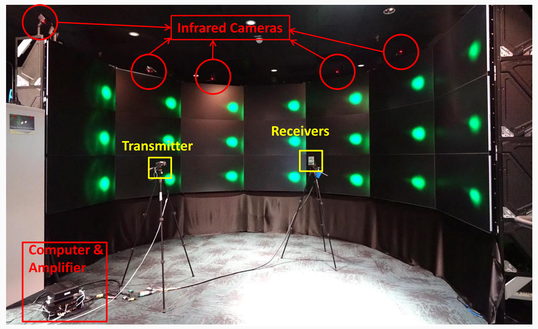
**Letter Direction Model**: We can represent letters using the direction at each measurement point. We can divide the directions into 8 groups.

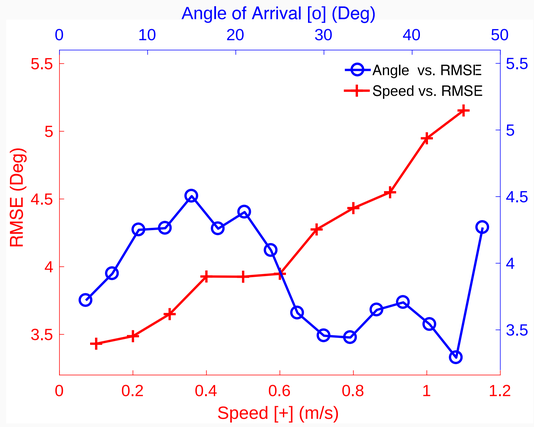



Directional DTW (D-DTW), hidden Markov model(HMM) complete classification based on letter direction model.

## 5. Experiments

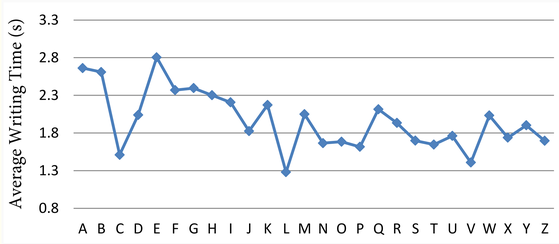
System accuracy was tested using ART system in KAUST Visualization Lab.




12 volunteers were recruited to collect 3120 written letters according to the following instructions:

- Try to write each number according to a template;
- The duration of each gesture is around 2 seconds;
- Sit around 1 metre in front of the receiver array;
- The movement of the hands should be within a square of 80 cm by 80 cm centered around the receiver array;
- Repeat each letter 10 times.




## 6. Results Evaluation

Average AOA estimating time on different machines:

| Machine | Per Measurement (ms) | Per Letter (s) |
|---|---|---|
| Dell T7500 | 1.2 | 0.12 |
| Macbook Pro | 3.5 | 0.34 |
| MITXPC M350 | 34.1 | 3.32 |

Average classification time and accuracy for different algorithms:

| Method | $T_{avg}$ (ms) | Accuracy (%) |
|---|---|---|
| DTW | 1054.3 | 91.92 |
| D-DTW | 185.7 | 97.21 |
| RD | 0.1 | 90.87 |
| RD-DT | 1.2 | 96.25 |
| NN | 15.4 | 96.47 |
| HMM | 6.9 | 96.92 |

$T_{avg}$ is the average classification time per letter.

## 7. Conclusion

- We presented an ultrasonic air-writing system for English letters.
- Classification performance is evaluated for both training-free and training-based classification methods.
- For the future work, the authors aim to develop algorithms for word recognition that can adapt to different writing styles.

## Reference

[1] Chen H, Ballal T, Saad M, et al. Angle-of-arrival-based gesture recognition using ultrasonic multi-frequency signals[C]. Signal Processing Conference (EUSIPCO), 2017 25th European. IEEE, 2017: 16-20.
[2] "UBAS: Ultrasound Based Air-writing System" (under preparation)