WiHF: Enable User Identified Gesture Recognition with WiFi

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Motivation: Gesture Recognition

Smart Home

Virtual Reality

Security Surveillance

The Robots of Dawn :

"Every time I lift my arm, it distorts a small electromagnetic field that is maintained continuously across the room. Slightly different positions of my hand and fingers produce different distortions and my robots can interpret these distortions as orders. I only use it for simple orders: Come here! Bring tea! and so on."

--- Isaac Asimov, 1983

It brings security concerns without the performer's identify.

Motivation: User identification

User identified gesture recognition.

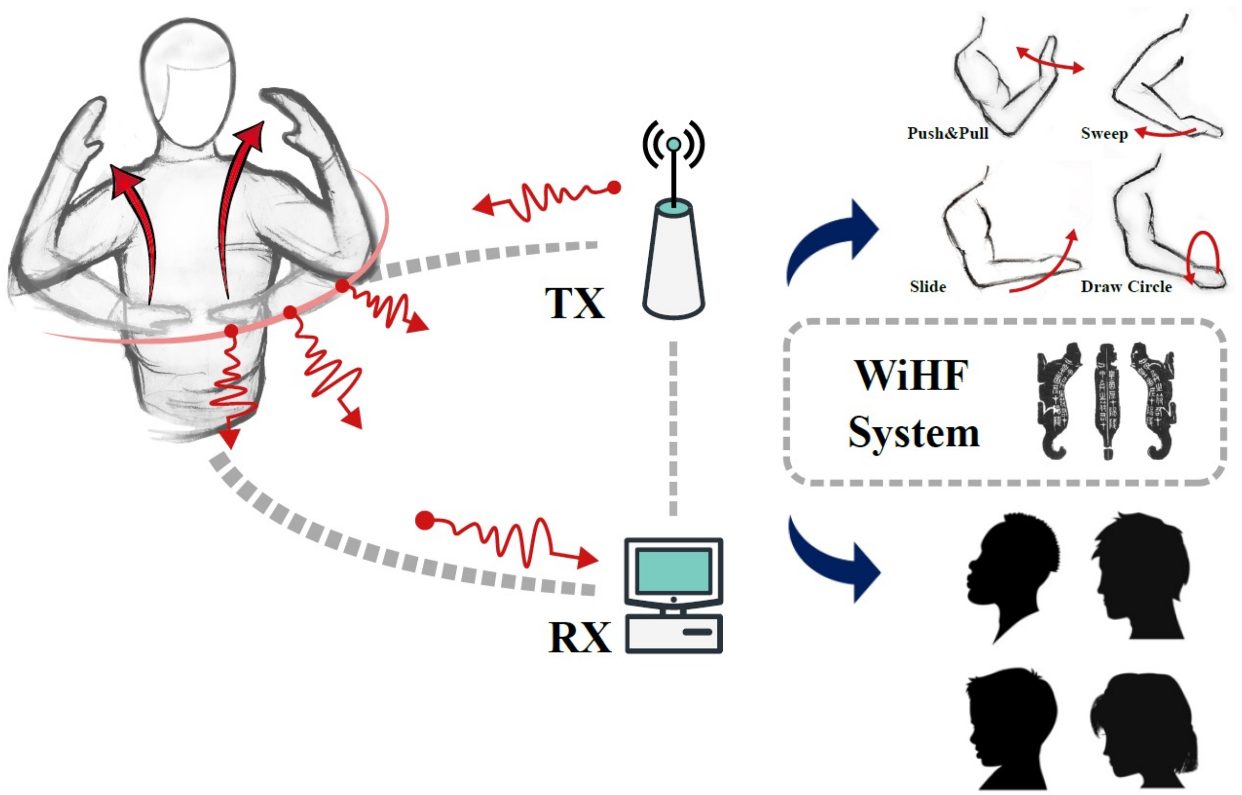
The semantic meaning of diverse gestures & who I am?

Hufu – Authorization of the Troop

Military messages

Authenticate the holder

Motivation: Applications



User identified gesture recognition:

- Access control
- Content recommendation
- VR customization

WiFi based User Identification

User identification

The human gait:

- WifiU UbiComp '16
- Wiwho IPSN 16'
- AutoID AAAI 18'

The location-oriented activities:

- WiPIN GLOBECOM '19
- Cong Shi et MobiHoc 17'

Comparable work

WiID

ACM IMWUT '18 &
UbiComp '18

- known gesture information
- cumbersome for cross-domain scenarios

WiHF: Problem Statement

Can we identify the performers while conveying the semantic meaning simultaneously?

- Feature design: Recognize gestures while identifying users *simultaneously*.

Preliminary and Observation

Theoretical support:

- The arm gestures are representative for user identification.

  --- WiID, Ubicomp 18'
- A domain-independent feature for cross-domain scenarios.

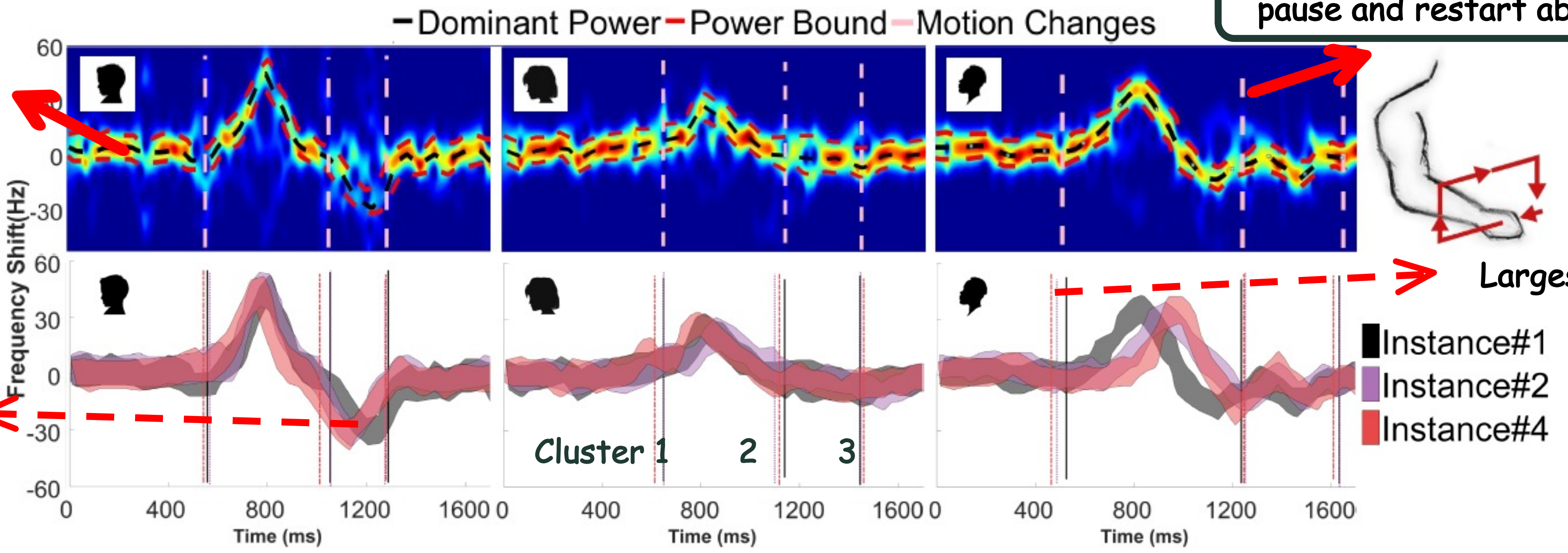
  --- Widar3.0, Mobisys 19'

Experimental observations:

Motion changes, such as pause and restart abruptly

Power-based paths: Dominant power & power bound

Temporal shift



Largest period < 70ms

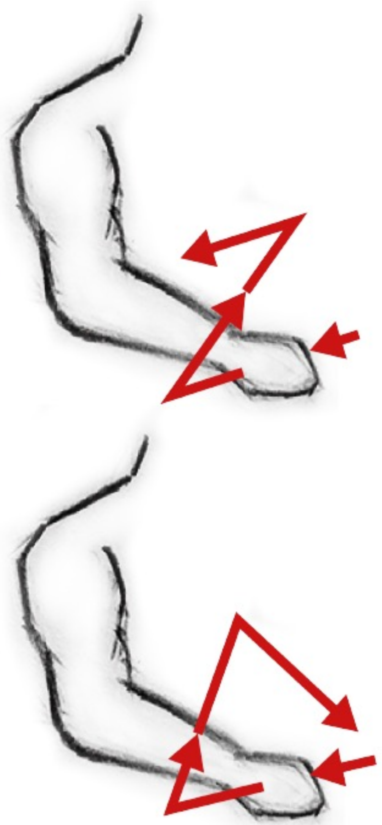
WiHF: Problem Statement

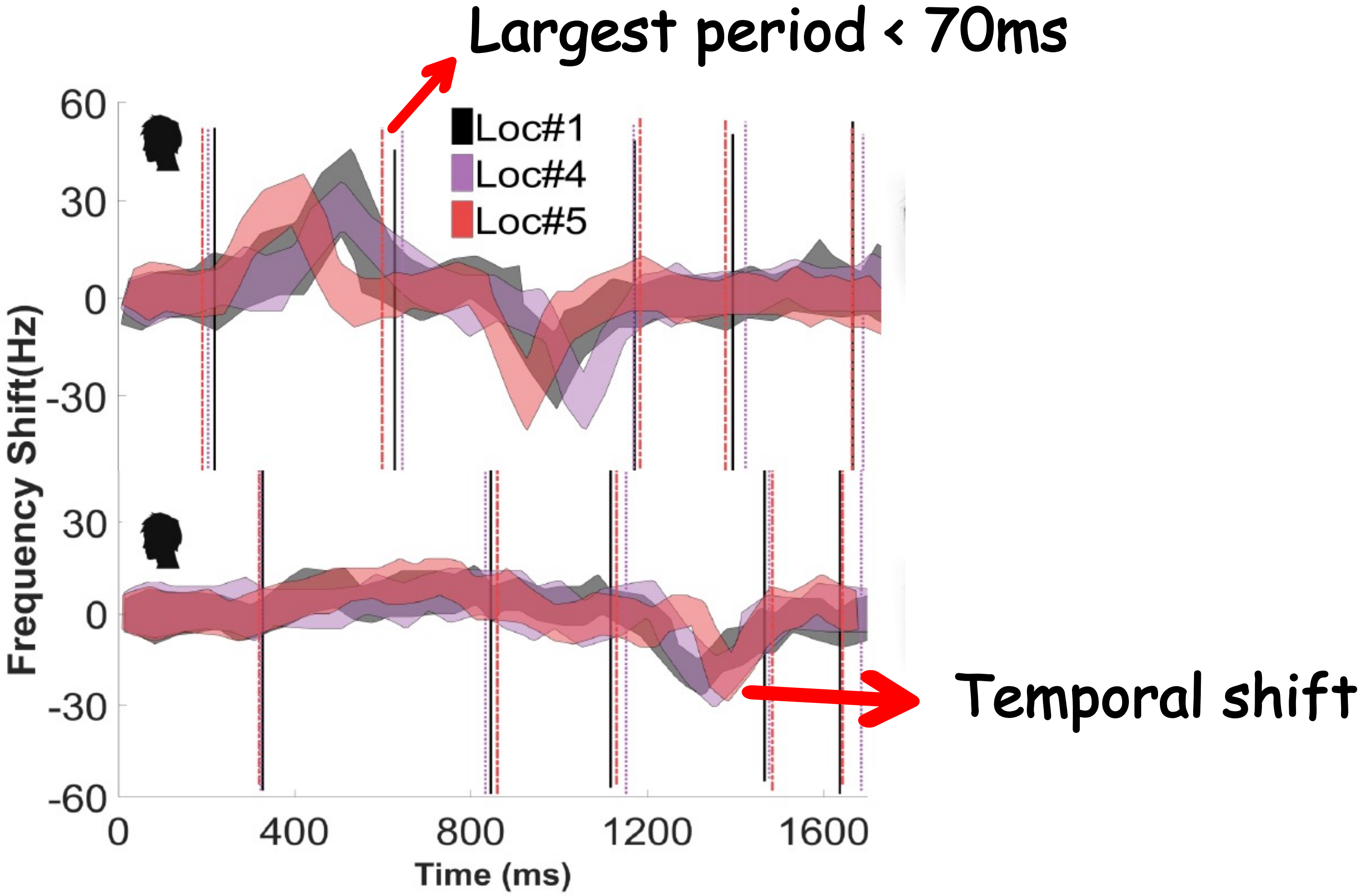
Can we identify the performers while conveying the semantic meaning simultaneously?

- Feature design: Recognize gestures while identifying users simultaneously.
- Cross-domain: Unnecessary extra efforts when gestures are performed in new domains.

Preliminary and Observation

*The **stability** across domains:*





WiHF: Problem Statement

Can we identify the performers while conveying the semantic meaning simultaneously?

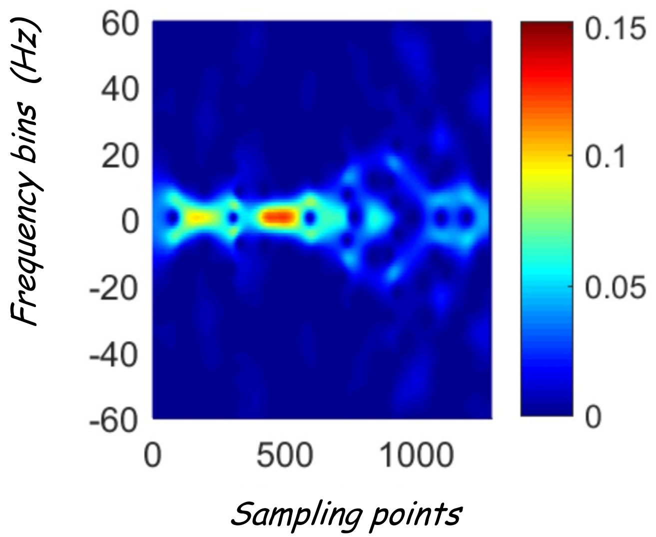
- Feature design: Recognize gestures while identifying users collaboratively.
- Cross-domain: Unnecessary extra efforts when gestures are performed in new domains.
- Computation efficiency: Efficient enough to be running in real time.

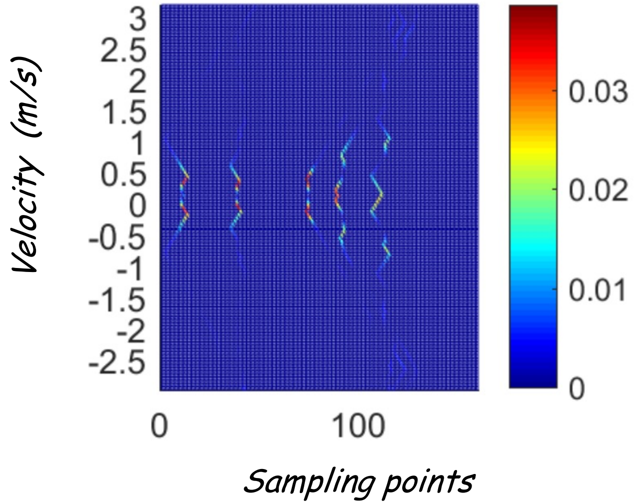
Pattern Extraction

To obtain motion change pattern *efficiently* :

- *Derive the spectrogram of denoised WiFi signals using STFT*
- *Associate the derivative of the spectrogram with motion changes*

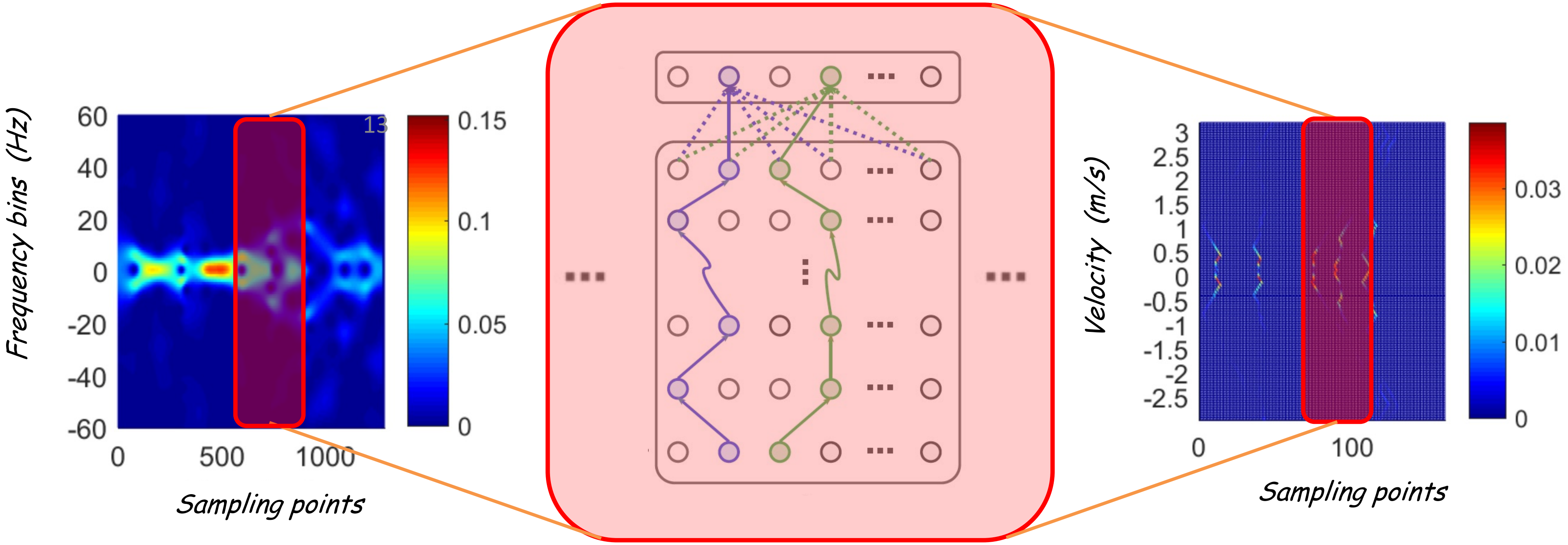
Derivative derivation of the spectrogram is computation-intensive





Pattern Extraction

Borrow the idea of Seam Carving Problem in computer graphics for content-aware image resizing.



WiHF: Problem Statement

Can we identify the performers while conveying the semantic meaning simultaneously?

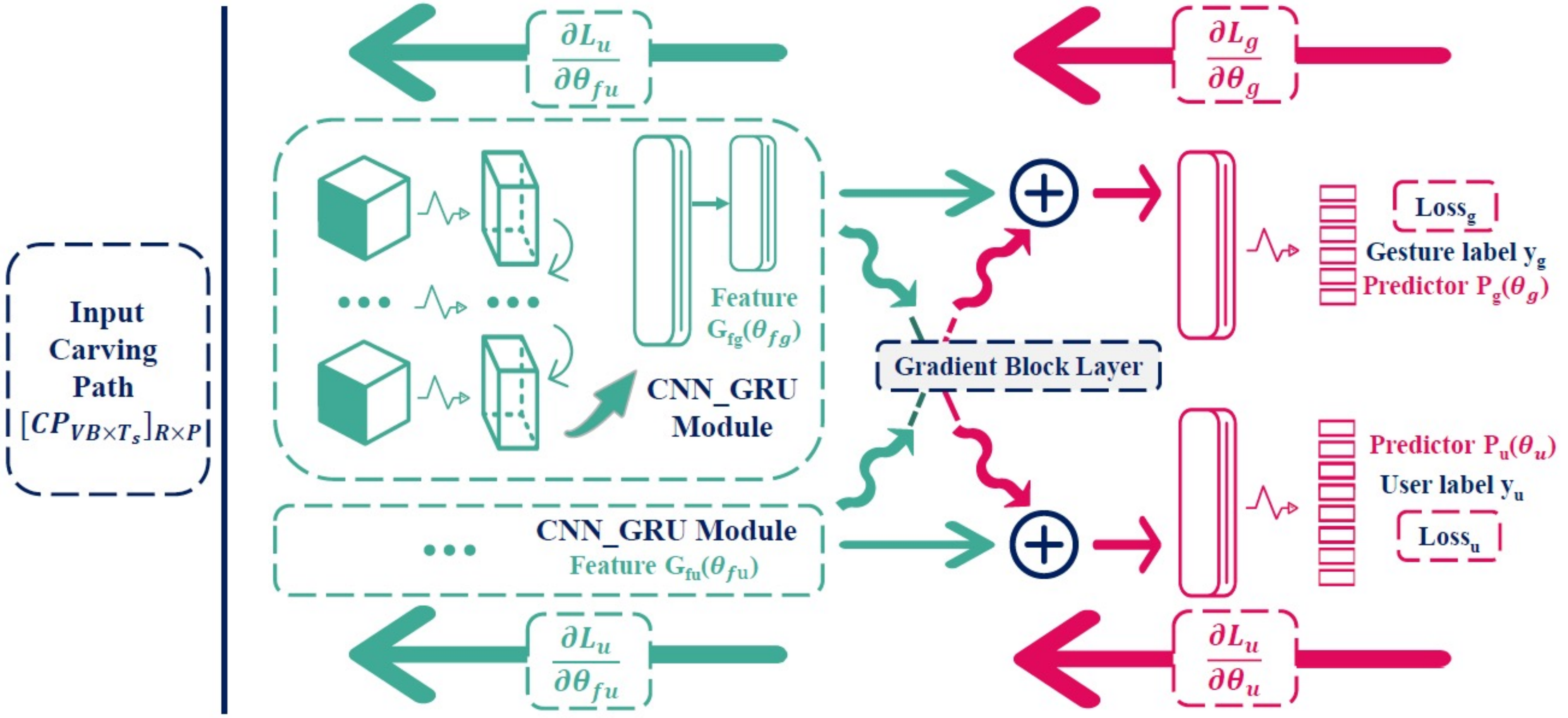
- Feature design: Recognize gestures while identifying users collaboratively.
- Cross-domain: Unnecessary extra efforts when gestures are performed in new domains.
- Computation efficiency: Efficient enough to be running. in real time.
- Dual tasks: bootstrap each other by learning collaboratively.

Collaborative Dual-task

Collaborative learning for dual tasks:

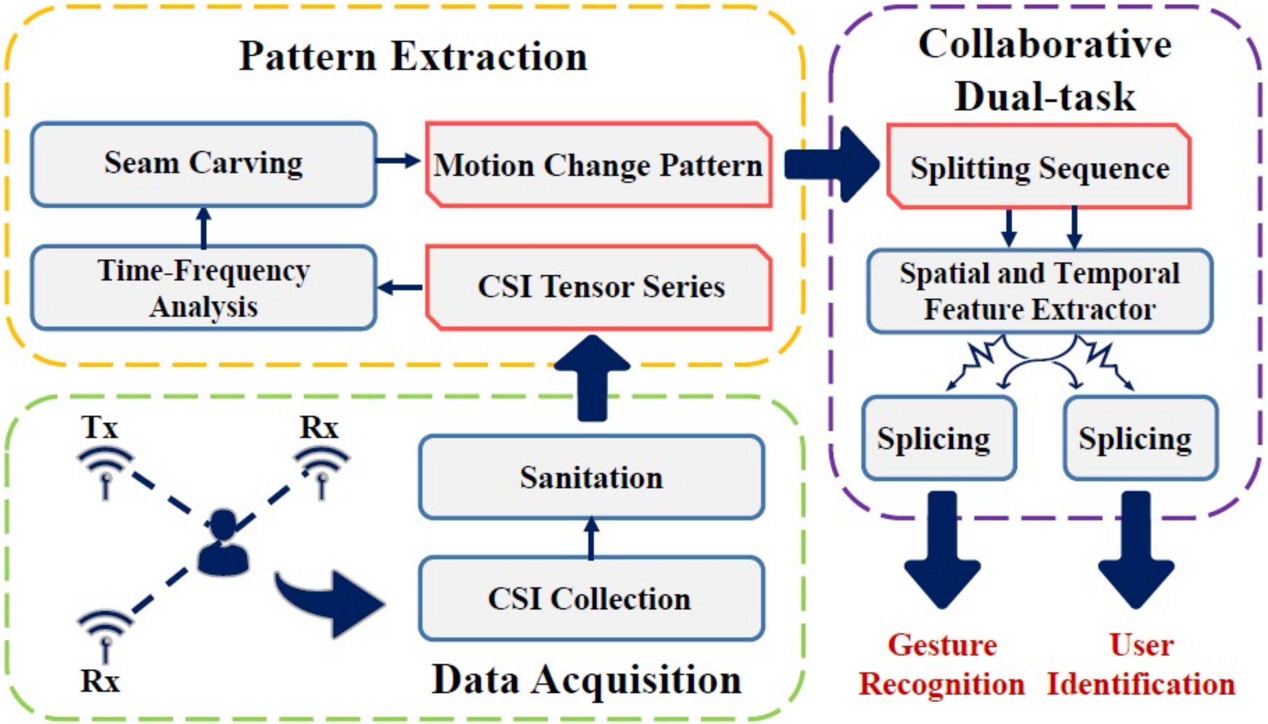
Feature splicing using the gradient block layer (slicing factor = 0)

- *Predict collaboratively while avoiding the loss propagations.*



WiHF: Pipeline

- Channel State Information (CSI) Preprocessing.
- *Motion change pattern extraction.*
- *Collaborative dual-task Deep Neural Network (DNN).*



Dataset

Widar3.0 public dataset:

- *The dataset can be found in http://tns.thss.tsinghua.edu.cn/widar3.0/index.html.*
- *9 gestures x 16 users x 75 domains (3 environments x 5 locations x 5 orientations).*

- *In use: 9 gestures x 9 users x 75 domains .*

Feature Dataset	***Comment***
HuFu Mini (HuFuM)	Compare the cross-domain gesture recognition with Widar3.0
HuFu Extend (HuFuE)	Explore the impact of gesture duration on user identification
HuFu	Explore the impact of gesture complexity on user identification

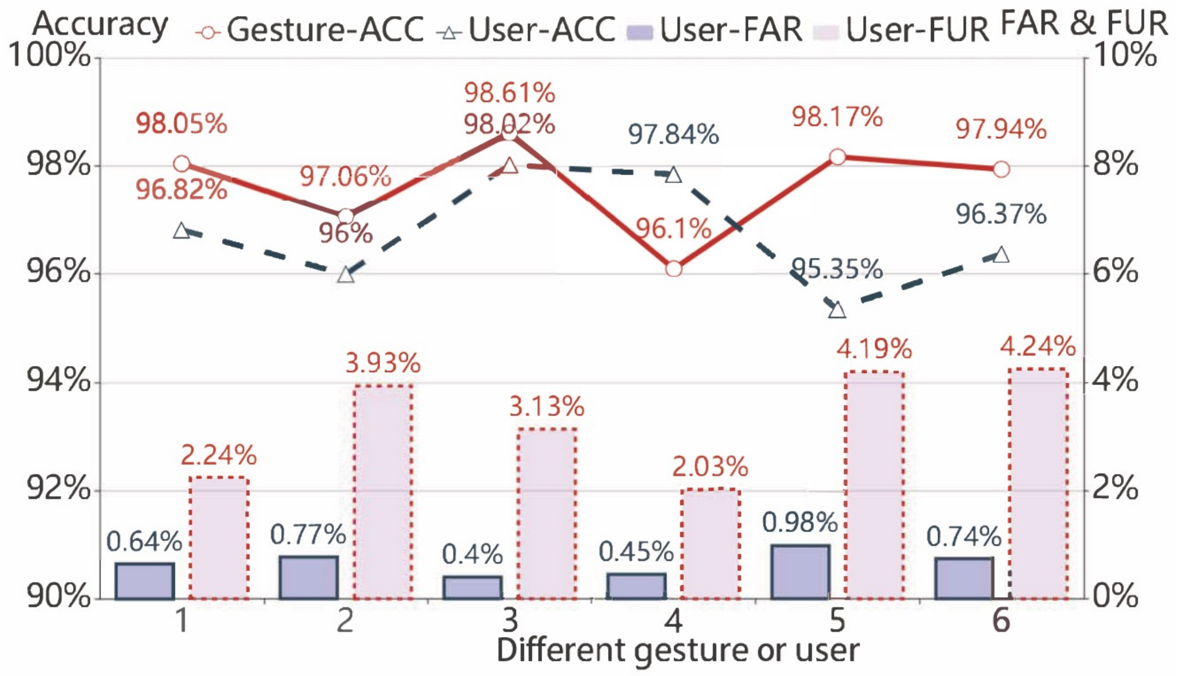
Evaluation

Metric:

- $ACC = \dfrac{TruePositive}{TruePositive + FalsePositive}$
- $FAR = \dfrac{FalsePositive}{FalsePositive + TrueNegative}$
- $FUR = \dfrac{FalseNegative}{FalseNegative + TruePositive}$

Accuracy (in-domain):

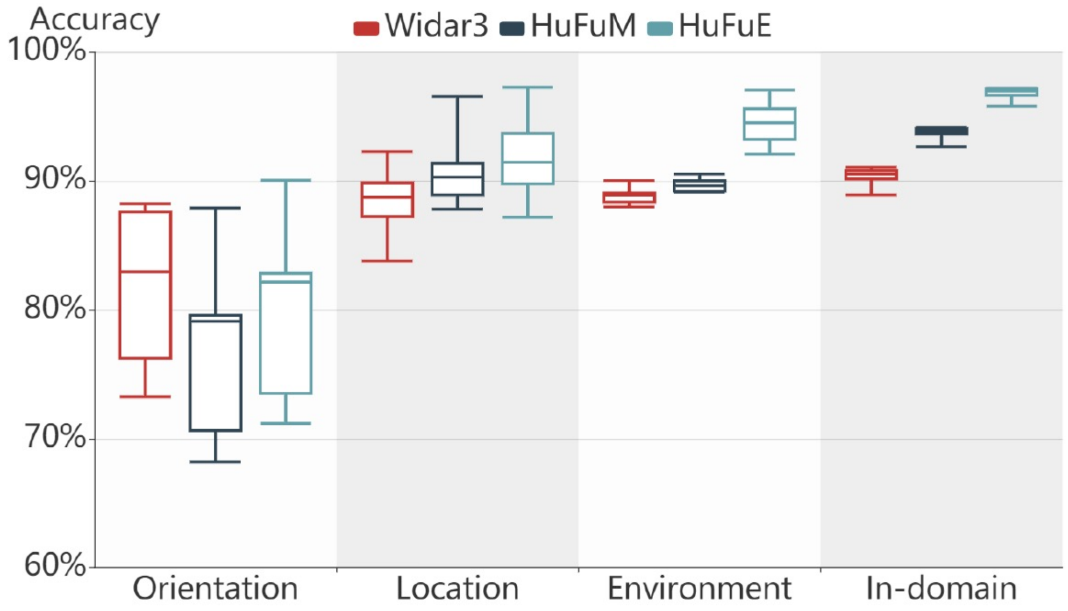
- User identification: 96.74%
- Gesture *recognition: 97.65%*



Evaluation

Cross-domain gesture recognition:

- *WiHF achieves comparable performance with the-state-of-the-art work (Widar3.0 Mobisys19') across domains.*



Latency:

- *The processing time of WiHF is reduced by 30x.*

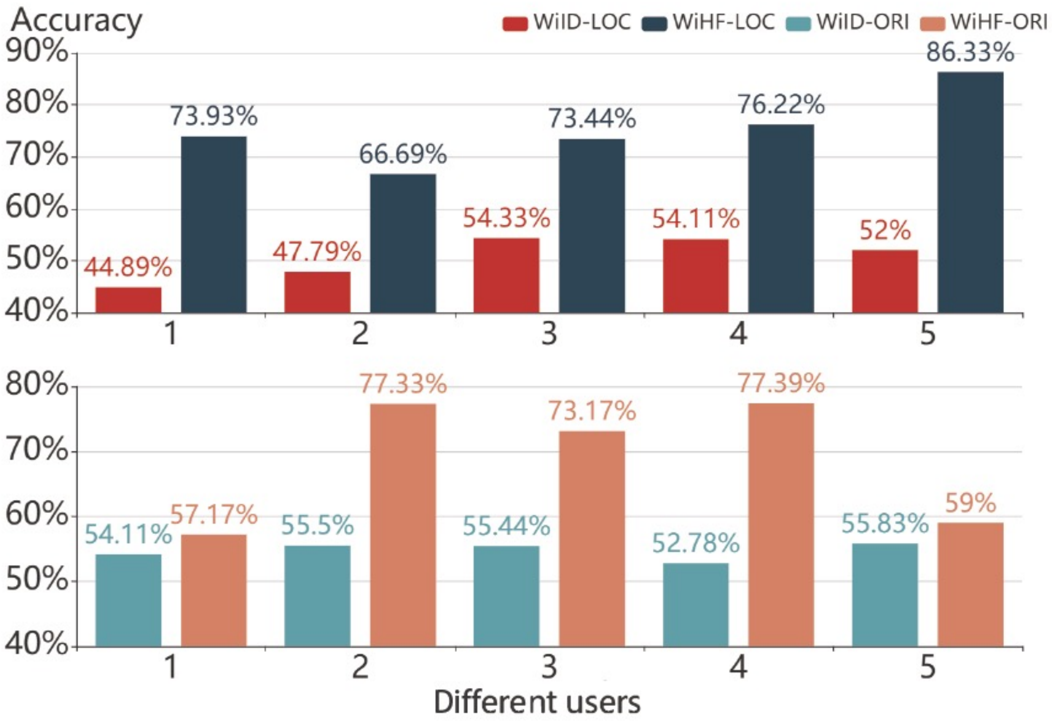
	Widar3	HuFuM	HuFuE	HuFu
Signal Processing	0.162s	0.992s	1.312s	1.557s
Feature Extraction	70.29s	0.194s	0.358s	0.379s
Total Time Consumption[a]	70.61s	1.462s	2.162s	2.488s
Gesture Duration	1.619s	1.619s	3.238s	3.669s

[a]It includes procedures for loading data, signal processing, feature extraction and recognition & identification.

Evaluation

TABLE 3
Accuracy for the In-domain Testing on HuFu Feature Dataset

User Identification	WiID	WiHF
In-domain	68.95%	96.74%



Comparative study:

- *WiHF outperforms WiID for in-domain user identification.*

Cross-domain user identification:

- *Consistent performance with the observation.*
- *WiHF suffers severely for edge orientations.*

Evaluation

#Gesture		6	7	8	9
Gesture Recognition	In-domain	97.65%	96.14%	95.33%	93.11%
	Location	92.07%	85.81%	84.92%	83.81%
	Orientation	82.38%	74.46%	72.72%	74.55%
User Identification	In-domain	96.74%	97.19%	97.29%	95.33%
	Location	75.31%	68.00%	70.65%	71.36%
	Orientation	69.52%	66.43%	68.34%	70.59%
#User		6	7	8	9
Gesture Recognition	In-domain	97.65%	96.17%	96.99%	97.21%
	Location	92.07%	90.94%	91.62%	91.22%
	Orientation	82.38%	83.81%	79.62%	80.64%
User Identification	In-domain	96.74%	92.56%	93.76%	94.43%
	Location	75.31%	66.98%	64.70%	65.26%
	Orientation	69.52%	63.26%	55.86%	57.26%

[a] The target label denotes the test dataset.

WiHF satisfies the requirements of the smart home scenario.

Conclusions

- WiHF designs a domain-independent motion change pattern of arm gestures and a dual-task network that can recognize gestures and identify users collaboratively.
- WiHF achieves the comparable cross-domain gesture recognition with the state-of-the-art method, but the processing time is reduced by 30×.
- *WiHF demonstrates the feasibility of cross-domain user identification but requires sophisticated gesture design.*

Thanks!
Q&A

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“We can only see a short distance ahead, but we can see plenty there that needs to be done.”——Alan M. Turing

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—— Alan M. Turing ——