XGait: Cross-Modal Translation via Deep Generative Sensing for RF-based Gait Recognition

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Background

Gait-based person recognition

- A gait is a manner of limb movements made during locomotion (walking).
- Different individuals have different gait patterns.
- Gait recognition does not require a person to perform any specific active task.
Gait recognition solutions

- Video-based solutions require an unobstructed view of the person in good lighting.
- Wearable-based solutions need user to pick up or wear the device on the body.
Background

- **Existing Radio Frequency (RF)-based gait recognition**
  - Versatile and penetrates obstacles, and not affected by lighting conditions.
  - **Limitation 1**: Deployment of RF devices in the data collection area.
  - **Limitation 2**: Users visiting the target area to pre-collect a few instances.

RF sensing-based gait recognition system  
Redundant user registration (data collection) process.

Identity Confirmed!
Our solution

- XGait: Cross-Modal Translation via Deep Generative Sensing for RF gait recognition
  - Leverage the Inertial Measurement Unit (IMU) signal in modern mobile devices to simulate the RF signals that would be generated if the same person walked near RF devices.
  - Eliminate the need for prior RF data collection.

An application scenario of XGait

(a) Home: Gait registration using IMU  (b) Office: Gait recognition using RF signal
Our solution

1. IMU gait data

2. RF data generation and gait registration

3. RF gait data

4. Recognition result

RF transceiver

Identity confirmed!

Register at anywhere

RF sensing-based identification

XGait
Challenges

- **Diversity of RF devices**
  - Various RF signals operate at different frequencies and use different modulation methods.
  - Consistently extracting and representing essential gait features across different RF signals remains a challenge.

- **Intrinsic difference between IMU and RF signals**
  - Due to the complex nature of human walking patterns, it is difficult to derive corresponding RF data from IMU data using mathematical calculations.

- **Complexity of gait**
  - Gait is the coordinated movement involves 2 phases, 8 events, and 24 body parts.
  - Similarity of gait signals among different people further hampers the recognition accuracy.
Feasibility study

- **Correlation model**

  - Different gait induce correlated changes in RF and IMU spectrograms.
  - There exists a possibility of converting IMU data into RF data through a non-linear function.
XGait workflow

1) User Registration, 2) IMU-to-RF Translation, 3) Gait Recognition.
System design

- **RF/IMU signal processing and spectrogram generation**
  - Maximal Overlap Discrete Wavelet Transform (MODWT) for denoising.
  - Short-Time Fourier Transform (STFT) for spectrogram generation.

![MODWT decomposition](image)

- MODWT decomposition
- Reconstructed results
- Extracted IMU feature
System design

- **Spec2Spec generative network for IMU-to-RF translation**
  - Deformable Convolutional Network (DCN)-based spectrogram fusion.
  - Conditional Generative Adversarial Network (cGAN) architecture for translation.
System design

- **Spec2Spec neural network for IMU-to-RF translation**
  - DCN-based spectrogram fusion.
  - Spectrogram translation using cGAN architecture.

Illustration of the deformable convolution

![Diagram](image-url)

Training progress

![Graph](image-url)

Epochs

<table>
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<th>IMU</th>
<th>RF</th>
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System design

- **Spectrogram transformer for gait recognition**
  - Shifted spectrogram patches, patch embedding layer, locality self-attention mechanism.
  - Address the data-hungry nature and complex training requirements of conventional transformer models.
Experimental settings

- **Data collection**
  - Wi-Fi, LoRa, mmWave RF devices and different mobile devices.
  - Indoor, outdoor, and through-wall experiments.

- **Metrics**
  - Top-N accuracy: this measures how frequently the correct user appears within the top N predictions.
Experiment results

- **Overall performance**
  - The Top-1 accuracy for LoRa, Wi-Fi, and mmWave are 96.21%, 92.14%, and 96.97%, respectively.
  - Top-3 accuracy values are above 99%.

- **Comparison with baselines**
  - AGait (RF-based), Gait-Watch (IMU-based), and WiFiU (RF-based with explicit features).
  - XGait demonstrated comparable performance to state-of-the-art systems.
Conclusion & Future Work

- We introduce XGait, the first RF-based gait recognition system that addresses the key limitations of existing RF devices and explicit data collection methods.

- Our comprehensive evaluation shows XGait's exceptional performance, achieving over 99% Top-3 accuracy across diverse scenarios.

- Future work will be directed towards expanding the application of this system to other use-cases such as gait abnormality analysis.
Thank you!