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at Northeastern University

SiMWiSense: Simultaneous Multi-Subject Activity Classification Through Wi-Fi Signals

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Why the Wi-Fi Sensing ?

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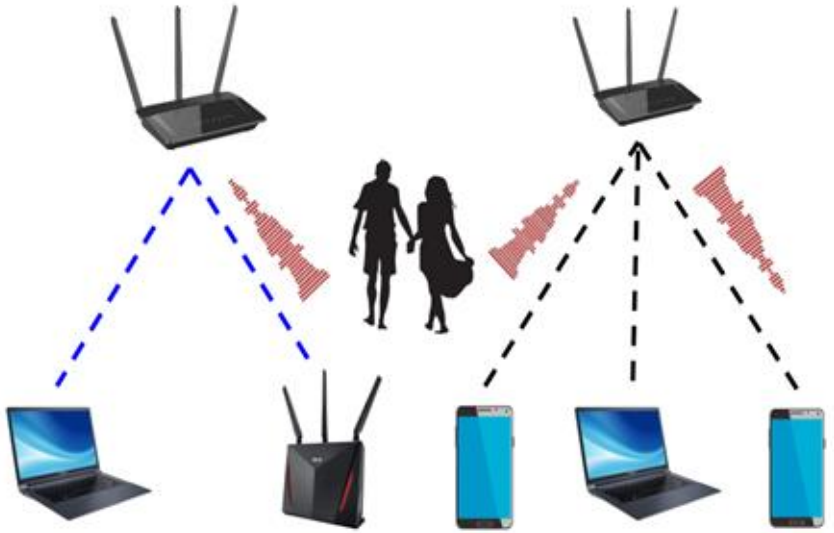
- Wi-Fi is one of the most pervasive wireless technologies
- Wi-Fi market is predicted to reach $4.9T by 2025[1]
- Beyond connectivity, Wi-Fi signals can be used to perform sensing tasks
- Example: Wi-Fi sensing can aid the computer vision applications in the edge devices



1. Wi-Fi Alliance, "The Economic Value of Wi-Fi: A Global View (2018 and 2023)," https://tinyurl.com/EconWiFi, 2021.

Traditional Wi-Fi Sensing Applications

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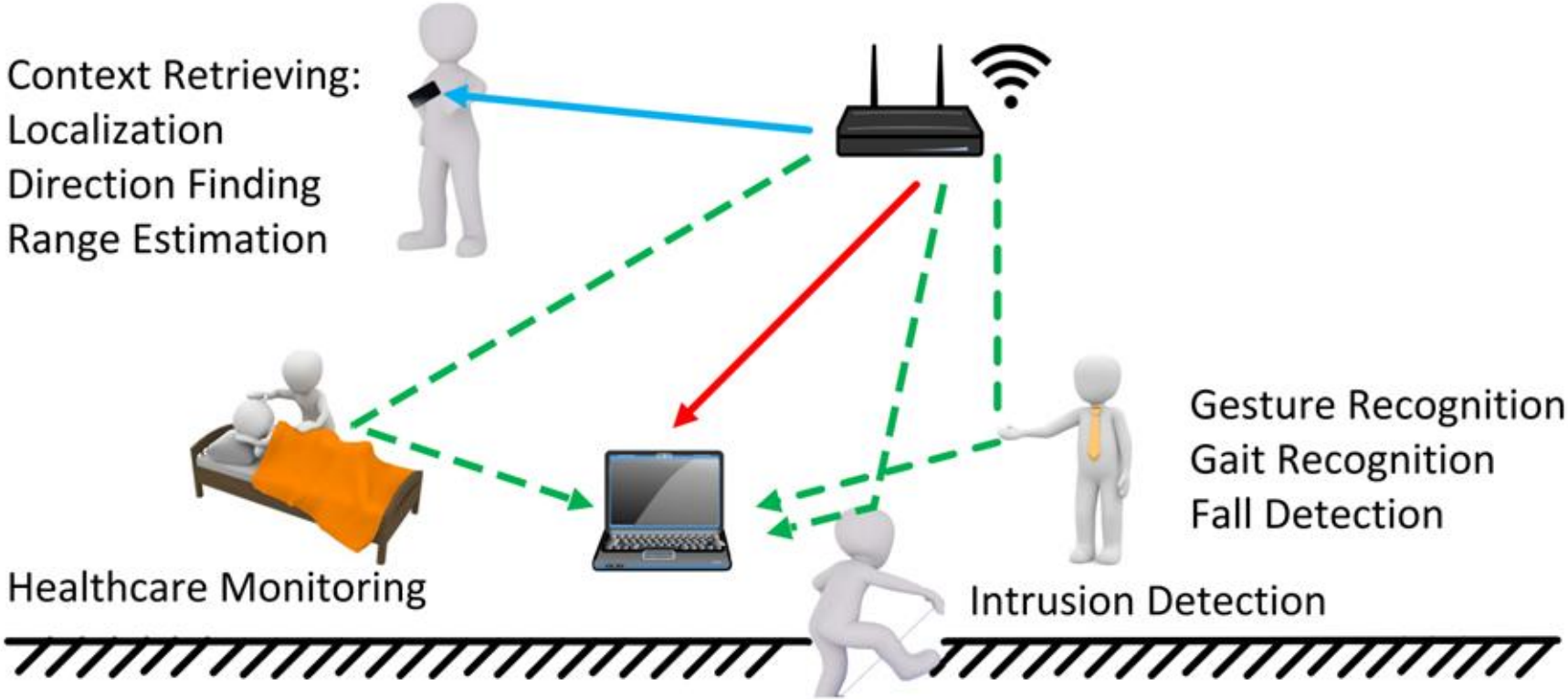

Image source: doi: 10.1109/ACCESS.2018.2812887

Wi-Fi Sensing in Metaverse

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- Metaverse is a virtual world where objects, places, and people are represented digitally
- It's use case includes education, remote working, social media interactions and gaming
- The global Metaverse market is predicted to reach 1500 B by 2029[1]

Image source: https://variety.com/2019/digital/news/oculus-quest-sales-data-1203239945/

1. https://www.fortunebusinessinsights.com/metaverse-market-106574

Wi-Fi Sensing in Metaverse

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- Need dedicated infrastructure
- Cost: $ (1500 - 4000)

- Could prevent **adoption**

✓ Wi-Fi sensing can address these challenges

VR Gloves

Image source: https://dev.to/codemaker2015/introduction-to-metaverse-1e6i
Image source: https://sensoriumxr.com/articles/metaverse-gear

Prior Work and Existing Challenges

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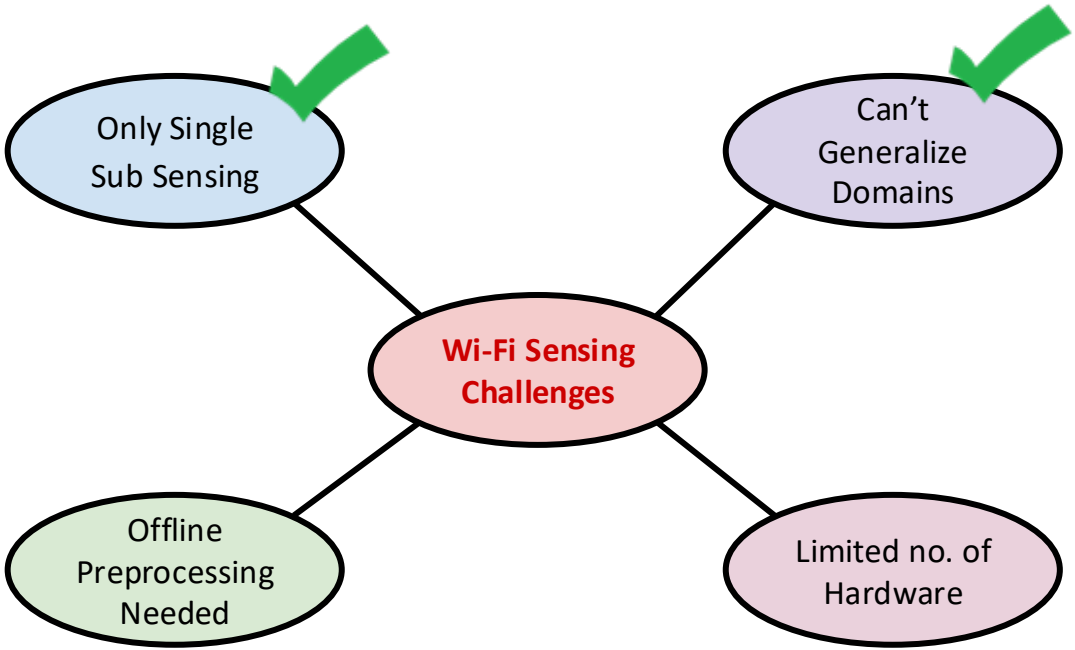
- R. Xiao, J. Liu, J. Han, and K. Ren, “OneFi: One-Shot Recognition for Unseen Gesture via COTS WiFi,” in Proceedings of the ACM Conference on Embedded Networked Sensor Systems (SenSys), pp. 206–219, 2021.
- F. Meneghello, D. Garlisi, N. Dal Fabbro, I. Tinnirello, and M. Rossi, “SHARP: Environment and Person Independent Activity Recognition with Commodity IEEE 802.11 Access Points,” IEEE Transactions on Mobile Computing, pp. 1–16, 2022.
- S. Depatla and Y. Mostofi, “Crowd counting through walls using wifi,” in 2018 IEEE international conference on pervasive computing and com munications (PerCom), pp. 1–10, IEEE, 2018.



Prior Work and Existing Challenges

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- **Challenges of Simultaneous Multi-subject Sensing with Current Approaches:**
  - If **n and m are the number of subjects and activities,** the number of classes becomes **m^n**
  - For example, **3 subjects and 10 activities** correspond to more than **1,000 classes**
- **Challenges of Current Generalization Approaches:**
  - Most of the work consider only a few activities[1]
  - Overall performance can be improved

1. F. Meneghello, D. Garlisi, N. Dal Fabbro, I. Tinnirello, and M. Rossi, "SHARP: Environment and Person Independent Activity Recognition with Commodity IEEE 802.11 Access Points," IEEE Transactions on Mobile Computing, pp. 1–16, 2022

Introduction on Wi-Fi Sensing

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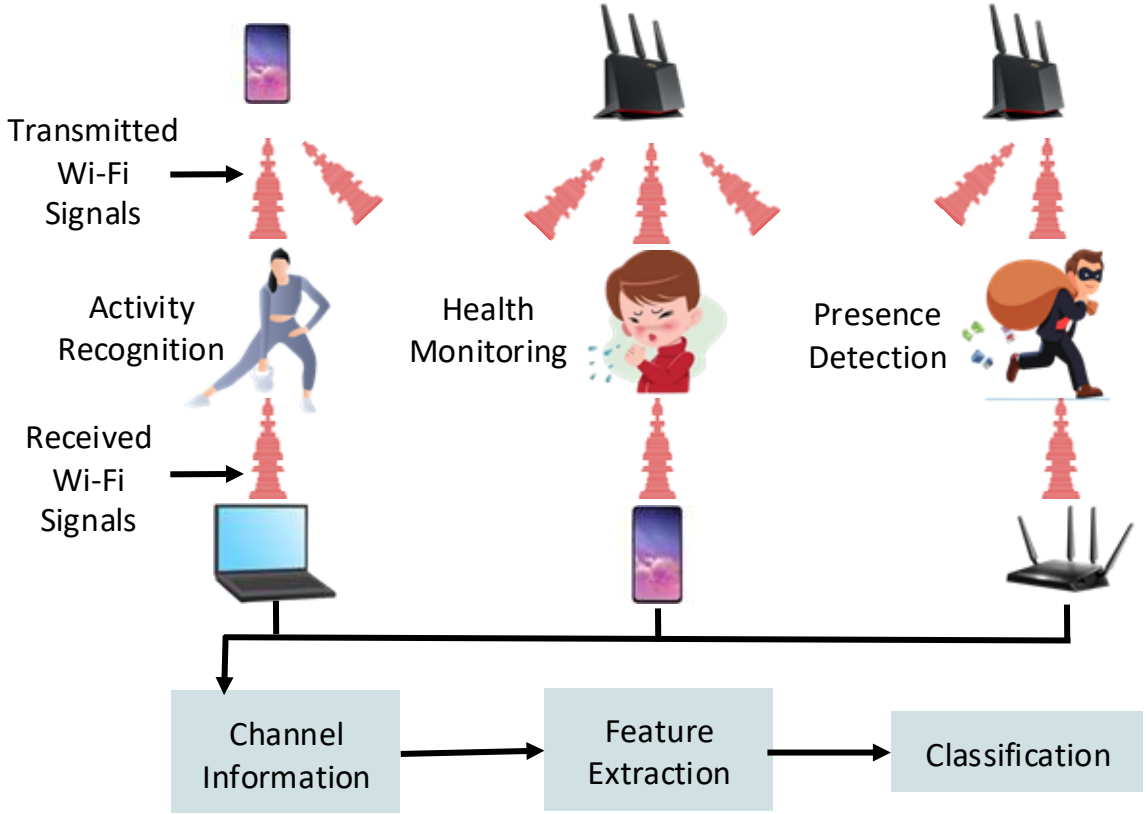
- Perceived by the changes in the channel frequency response (CFR).
- Main approaches are based on:
  - (i) Received Signal Strength
  - (ii) Passive Wi-Fi Radar
  - (iii) **Channel State Information (CSI)**



Simultaneous Multi-Subject Sensing

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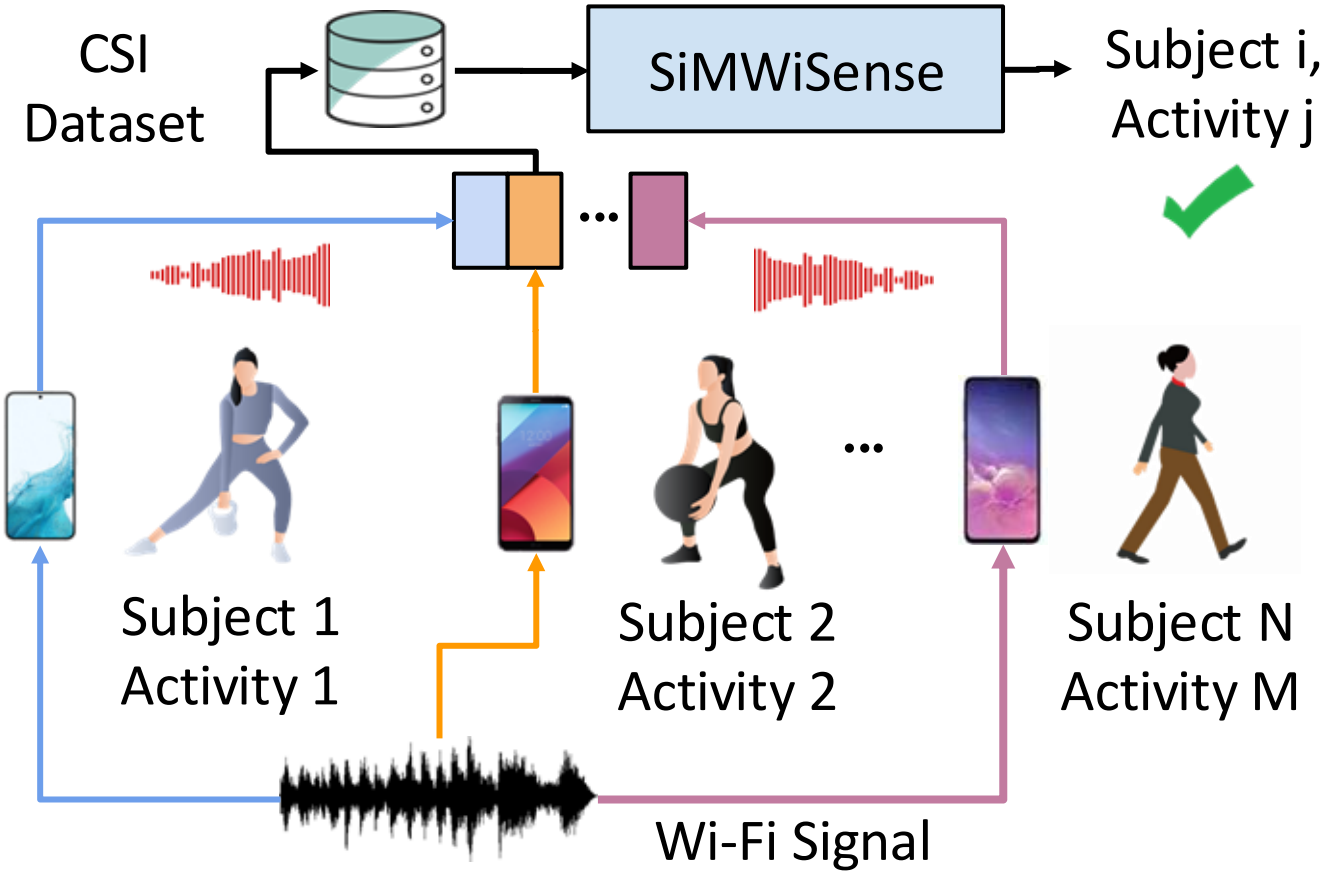

Experimental Proof of Our Intuition

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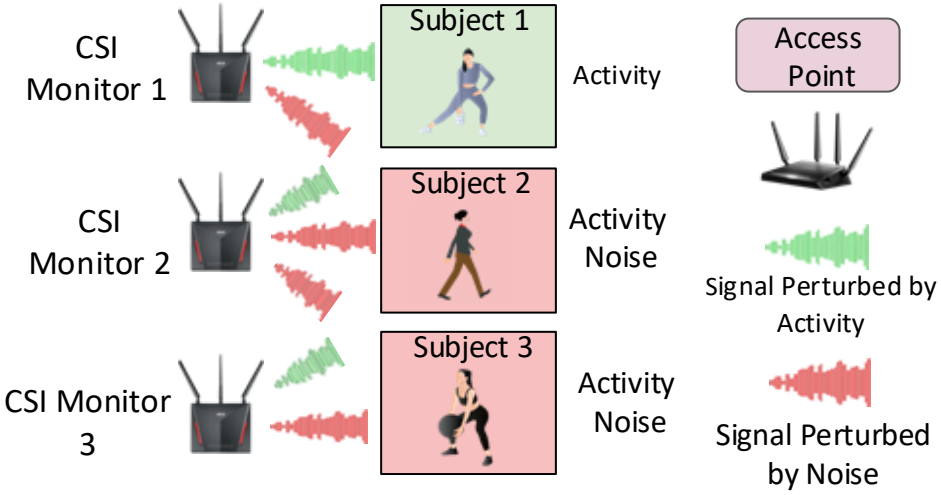
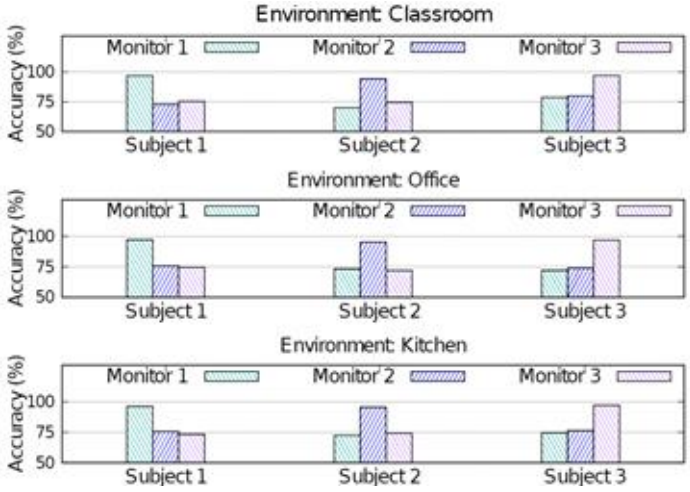
- Sensing proximity test is performed with 3 different subjects at 3 different environments
- With Monitor 1, subject 1 achieves 95%, whereas the accuracy of Subject 2 and Subject 3 decreases by 30% on an average.

Proximity test setup



Accuracy vs sensing proximity



SiMWiSense Overview

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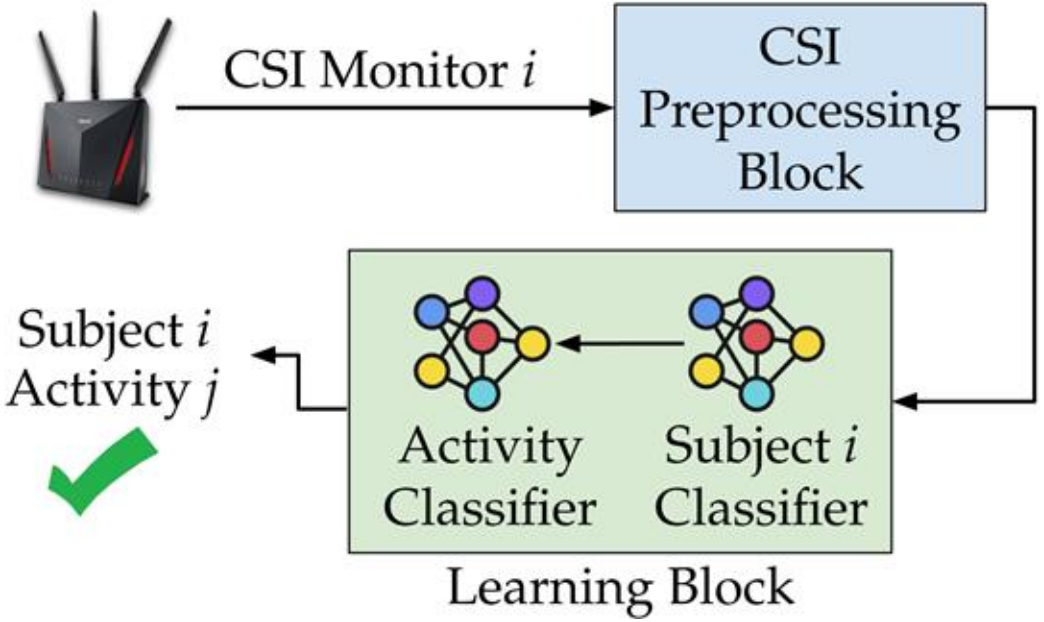
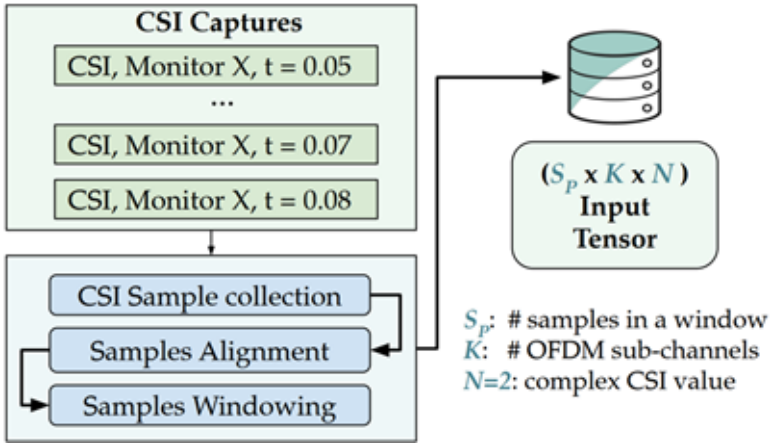
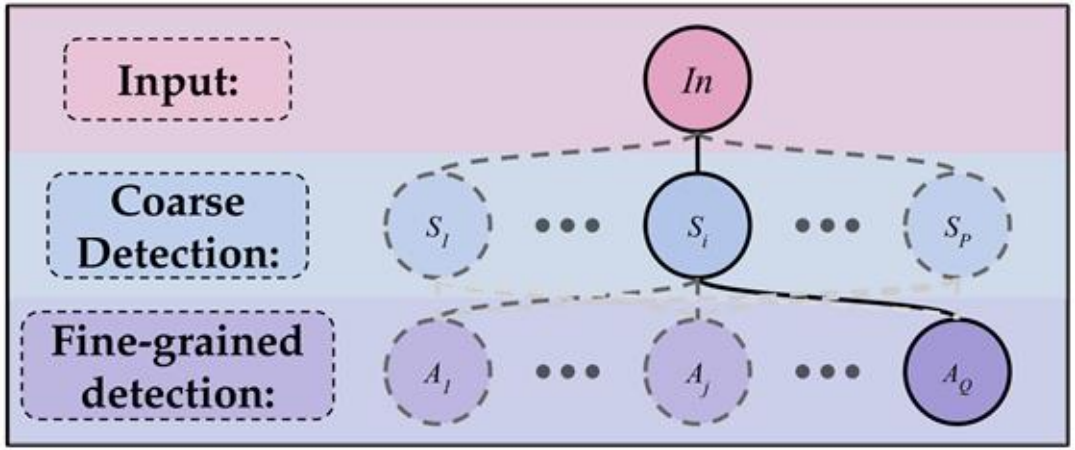


CSI Preprocessing Block



SiMWiSense Learning Block

- **Coarse Detection:** a deep learning (DL) model is used to discriminate **subjects n**
- **Fine-grained Detection:** another DL model is used to determine the **activities m**.
- Thus Complexity becomes **n + m** instead of m^n



Feature Reusable Embedding Learning (FREL)

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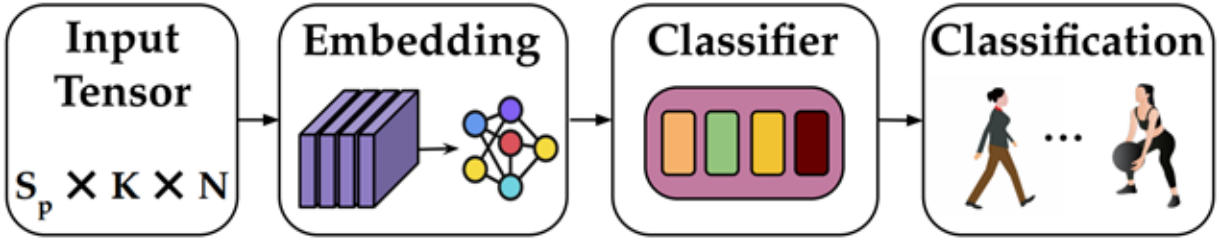

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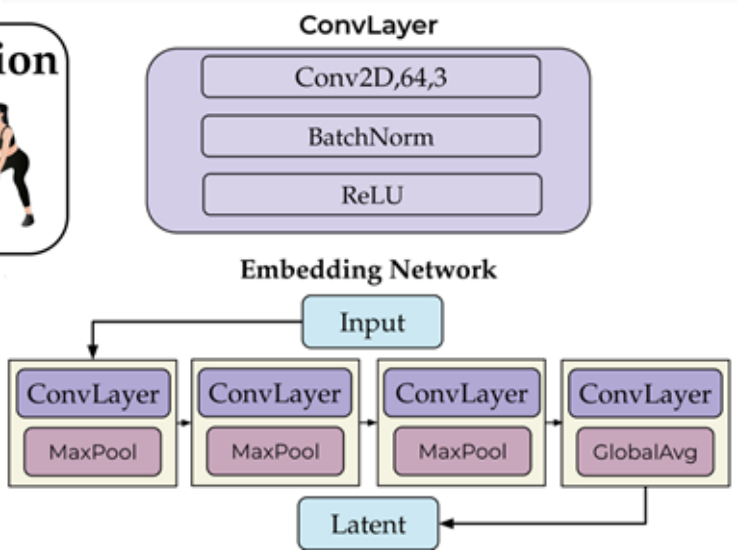

Embedding Network

- The embedding network and classifier are jointly trained with a mini-dataset like **Embedding Learning**.
- Then, like **Meta Learning**, we further optimize the classifier with a few samples.

Experimental Testbeds

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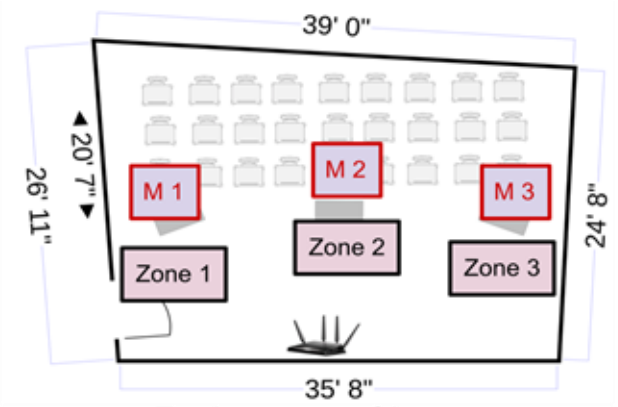
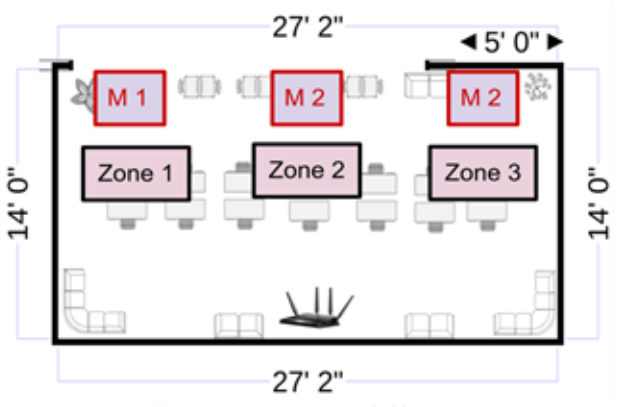
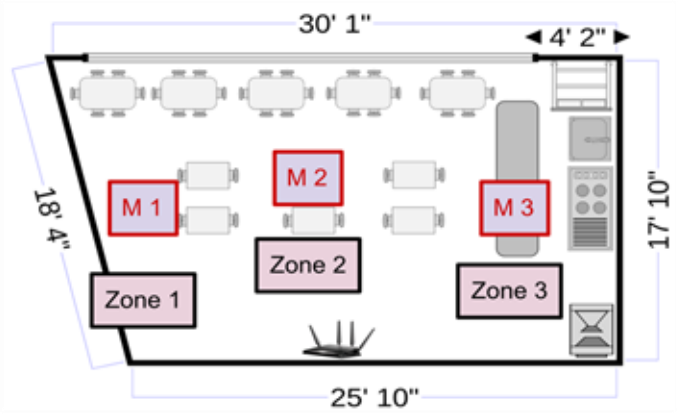


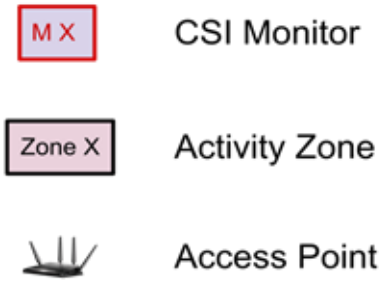
Environment: Classroom



Environment: Office



Environment: Kitchen



Data Collection Campaign

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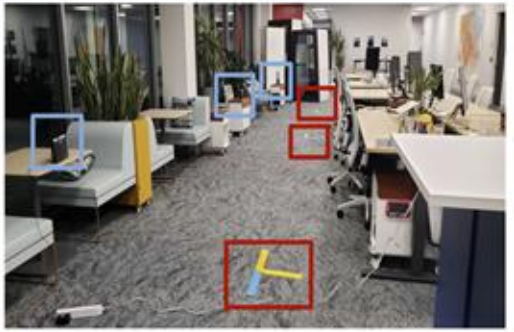
- Three CSI extractors are setup at a distance of 1.5-3.0 m
- Video Streams has been recorded as ground truth
- Data collection campaign is done with 3 different persons, 20 activities each in 3 different environment.

push	rotate	Hands up	waive	brush
clap	Sit	Eat	Wash hands	Bend forward
drink	call	kick	writting	read
Waive-sitting	Side bend	Check wrist	standing	Browsing phone

Classroom

Office



Kitchen

CSI Monitor

Activity Zone

Performance with Baseline CNN

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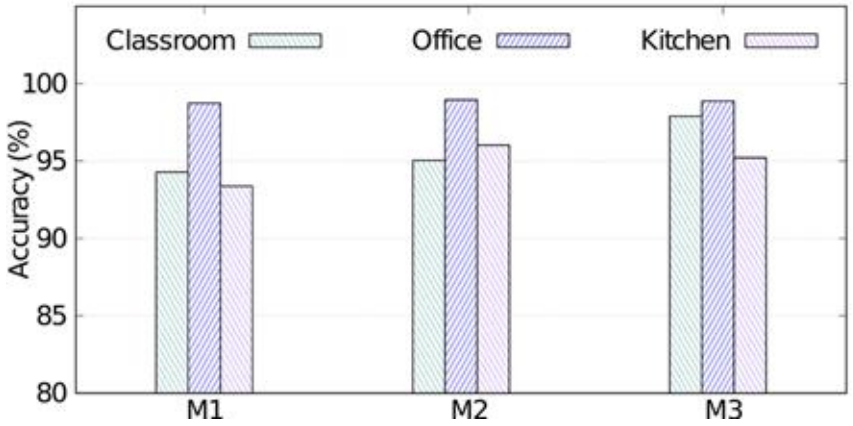
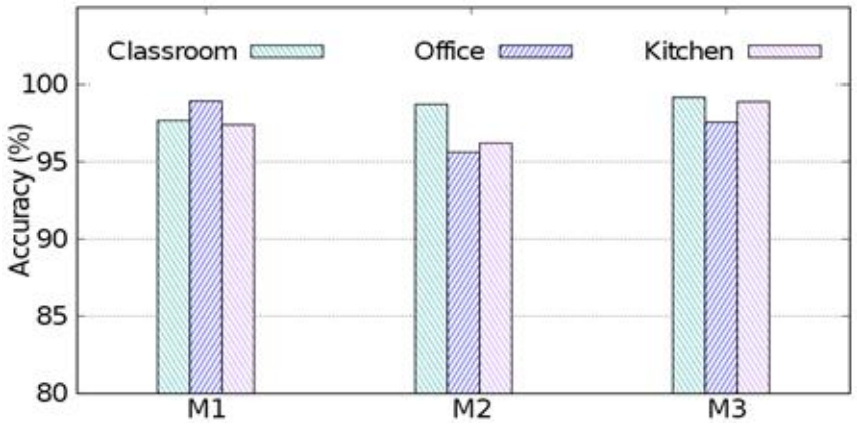
- Average subject identification accuracy of M1, M2 and M3 is 96.49%.
- With baseline CNN, Activity classification can achieve up to an accuracy of 97%.
- However, CNN cannot generalize to new environments or subjects

Subject Classification Performance



Activity Classification Performance



Performance of FREL as Subject Identifier

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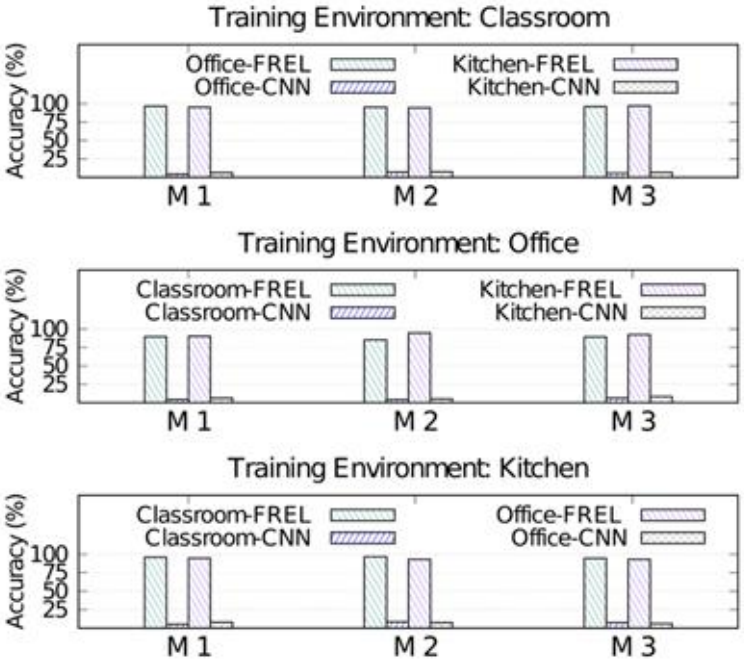
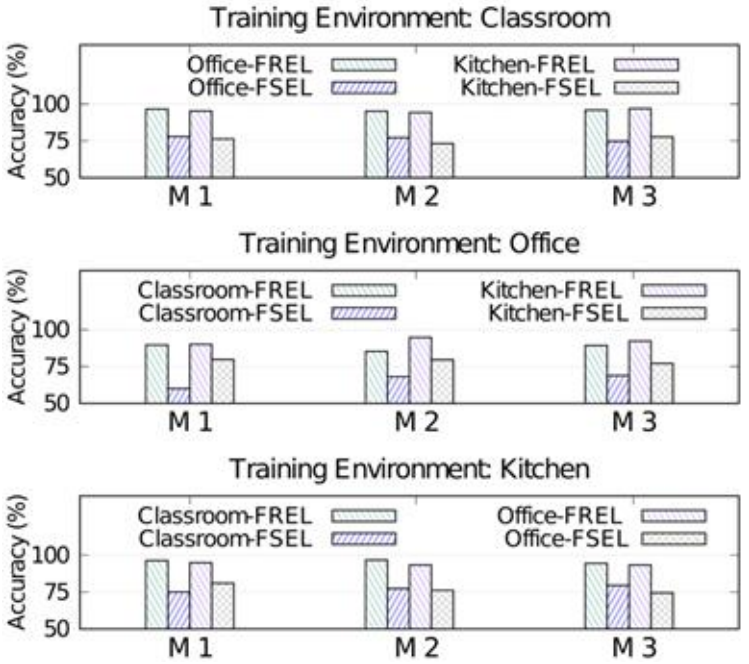
- In unseen environments, CNN only limits to 6.19% compared to the average performance of 93.53% for FREL
- **FREL** demonstrates an accuracy boost of 17.7% on an average in comparison to SOTA embedding model (FSEL)





Performance of FREL as Activity Classifier

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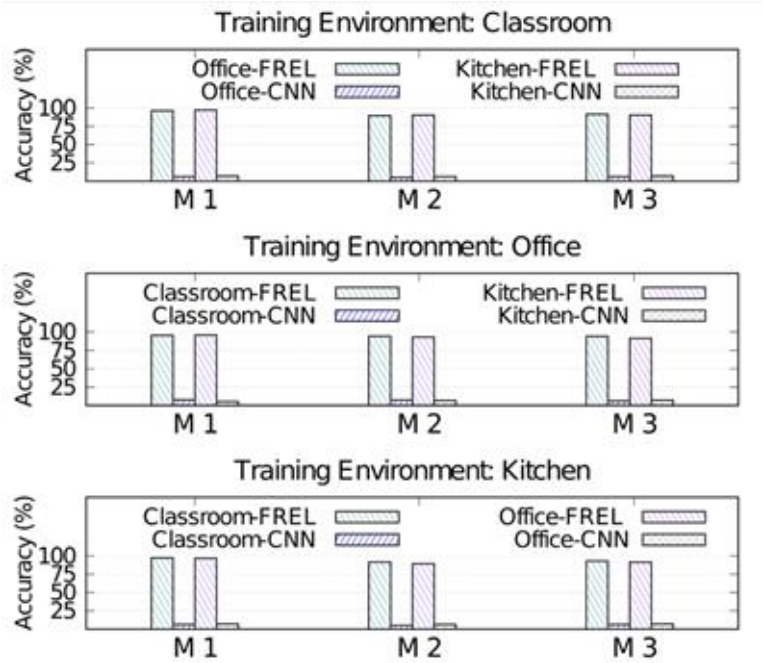
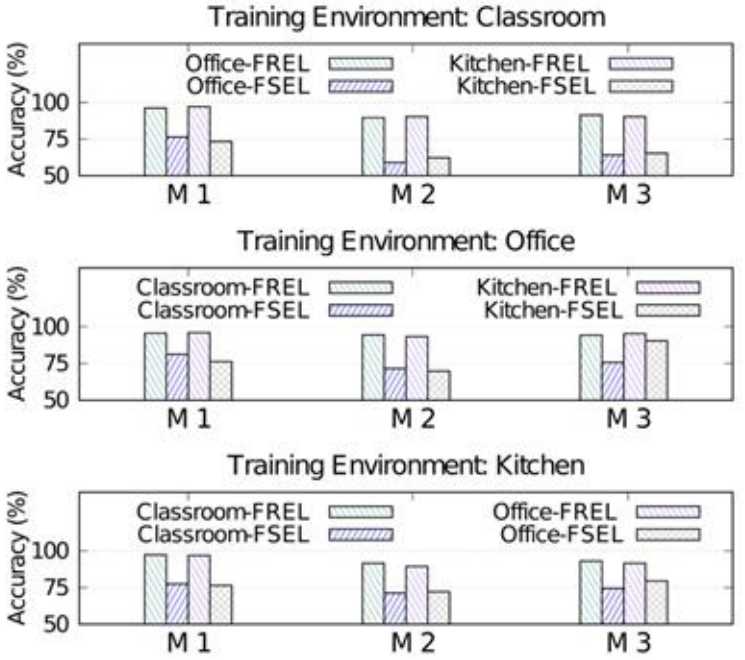
- In generalizing new environments, **FREL surpass CNN by 86.6%** on an average.
- **With 15s of new data FREL boosts** the performance of SOTA model (FSEL) by **17.5% on an average**.





Performance of FREL with Unseen Subjects

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- It can achieve an average **accuracy of 94%** while trained with one Monitor and tested with others.
- FREL enables any system to be trained only **on one monitor and deployed with n number of monitors.**

Key Findings and Limitations

- ✓ We present SiMWiSense, the first framework for multi-subject simultaneous activity classification using Wi-Fi
- ✓ To address the challenge of generalizing to new environments and subjects, a novel algorithm FREL is proposed which surpass the SOTA model

Limitations:

- ✓ The model still needs 15s of data from new environment to fine tune

Future Work

- Sensing without no additional data at all from new environment
- Sensing with larger band to have more sensing granularity

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Thank You