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WiSense 2025
The 2nd International Workshop on Pervasive Wireless Sensing and Edge Computing

PhysiFi: WiFi Sensing for Monitoring Therapeutic Robotic Systems

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Motivation

Physical Therapy is essential for patients recovering from limb-impairing strokes to:

- Regain mobility
- Restore limb functionality

Practicing Physical Therapists on Decline:

- In 2021 over 22,000 physical therapists left the practice[7]

Limitations of Current Autonomous Physical Therapy Systems Monitoring:

- Physical Therapist present monitoring exercises
- Camera based technologies

Wi-Fi Sensing

What is Wi-Fi Sensing?

Use of ambient Wi-Fi signals to detect changes in an environment.

Pros of Wi-Fi Sensing:

- Non-invasive
- Low-Cost
- Uses Channel State Information (CSI) between transmitter (TX) and receiver (RX)
- Can work in Non-Line-of-sight (NLoS)

Proposed Solution: PhysiFi

PhysiFi is a system that analyzes Channel State Information (CSI) from ambient Wi-Fi signals and employs a deep neural network (DNN) based model for robot assisted physical therapy monitoring.

The system has two goals:

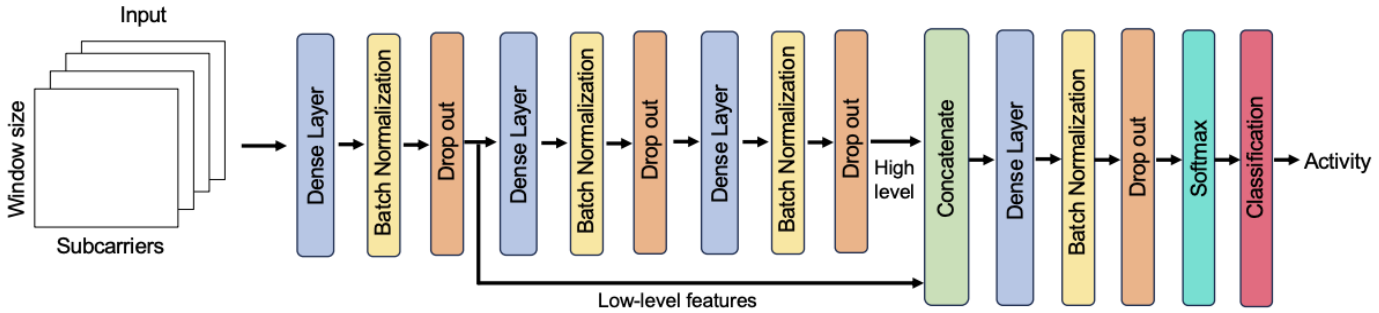
- Recognize robot assisted therapy movements
- Assess patient compliance

PhysiFi: Preprocessing

- **Step 1:** Gather raw CSI data
- **Step 2:** Utilize Hampel Filter to detect and correct anomalies.
- **Step 3:** Use window averaging to smooth temporal fluctuations.
- **Step 4:** Perform Principal Component Analysis (PCA) to reduce dimensionality and noise.

PhysiFi: Recognition Process

- **Step 1:** Extract low-level features
- **Step 2:** Process high-level features
- **Step 3:** Merge both feature sets for robust recognition.
- **Step 4:** Classify robotic movements and patient compliance.



DNN model architecture

Experiments

Setup

- Low cost ESP32-CSI-Toolkit
- One transmitter (TX) & one receiver (RX)
- CSI packet frequency: 100Hz
- Aluminum foil room divider

Activities:

- 3 basic arm movements

Data Collection:

- Activity time: 5 seconds, Rest/transition time: 5 seconds
- 15 times in a round robin fashion (total ~1 hour data)
- Extracted **amplitudes** from CSI + **preprocessing**: Window averaging, PCA

Split:

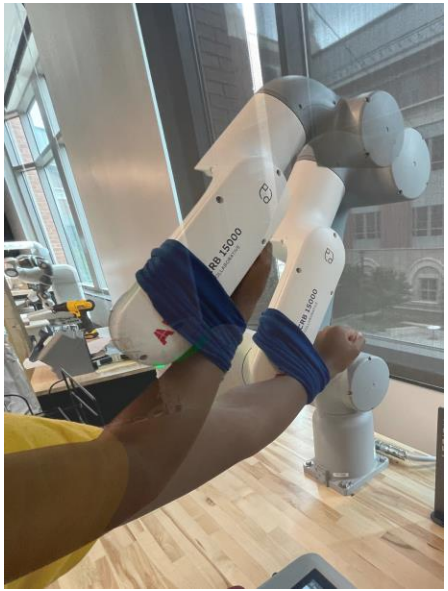
- **70% training** (robot only scenario)
- **30% test** (robot only scenario and human-arm strapped scenario combined).

Challenges

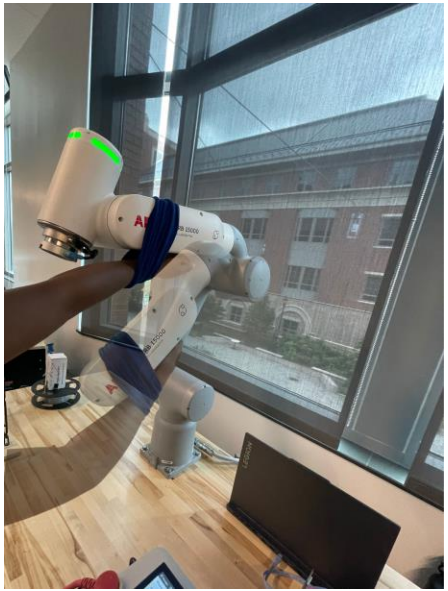
- **Environmental Noise:** WiFi CSI signals were affected by surrounding movement

- **Robot Location:** The robot could not be placed in a secluded environment, potentially introducing unintended signal interference.

Activities



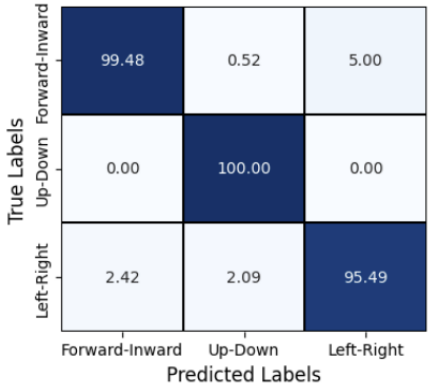
FORWARD-INWARD



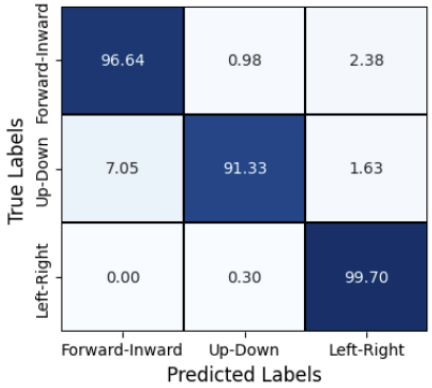
UP-DOWN

LEFT-RIGHT

Results



(a)



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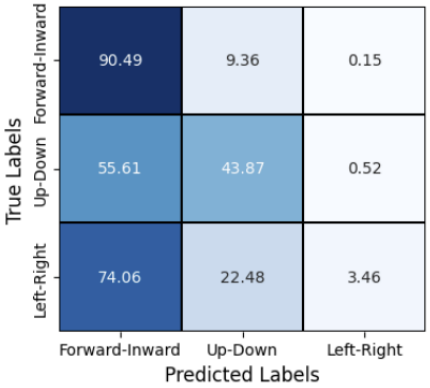
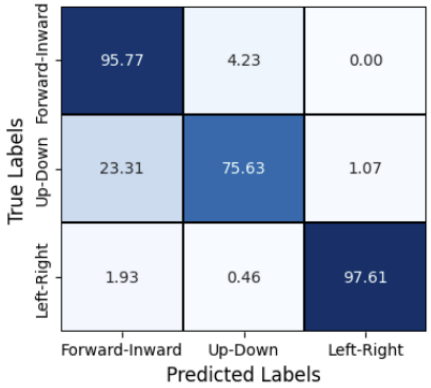


(c)



(d)

	Scenario	Accuracy (%)
a	Robot only	98.5%
b	Strapped Arm with full compliance (Volunteer 1)	95.9%
c	Strapped Arm without compliance (Volunteer 1)	44.2%
d	Strapped Arm with full compliance (Volunteer 2)	90.2%

Summary

Achievements:

- High accuracy compliance recognition
- Low-cost monitoring system
- Robustness across different users
- Privacy concerns addressed

Extensions:

- Exploring multi-limb rehabilitation scenarios
- Test performance in various environments with more volunteers
- Enhancing model generalization for partial compliance detection

Applications:

- Remote physical therapy monitoring.
- Assisting therapists in tracking patient progress.

Thank you!

Questions?

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