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# Denoising E-Textile Sensors for Real-World Kinematics Monitoring

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- **Introduction**
  - Motivation and state-of-the-art
- **Operating Principle of E-Textile Kinematics Sensors**
- **Measuring the Fabric Drift Error**
  - Experimental setup
  - Measurement observations
  - Model analysis
- **Correcting the Fabric Drift Error**
  - STEP 1: Initial condition calibration
  - STEP 2: Machine learning aided calibration
- **Conclusion and Future Work**

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# Motivation for Motion Capture “In-The-Wild”

## Healthcare

- Detection and Rehabilitation
- Parkinson’s, TBI, Concussion, Falls etc.

## Sports

- Optimize fitness and prevent injuries
- Rehabilitate in real-time, faster recovery.

## Healthy Individuals

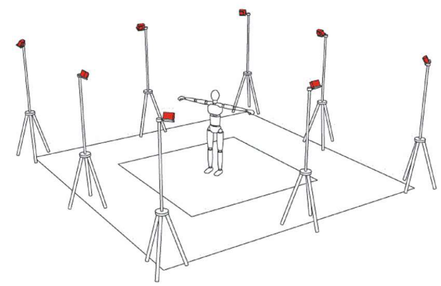
- Maintain fitness and create baseline data.
- Pre-onset detection and relevant measures.

## Human-Machine Interface, and Animation

**Widespread and significant impact**

## Biomedical Research

# State-of-the-art Motion Capture Technologies

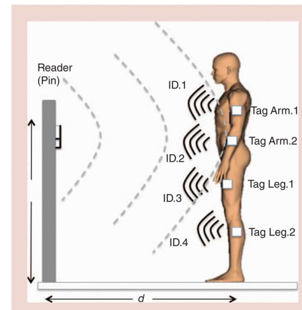


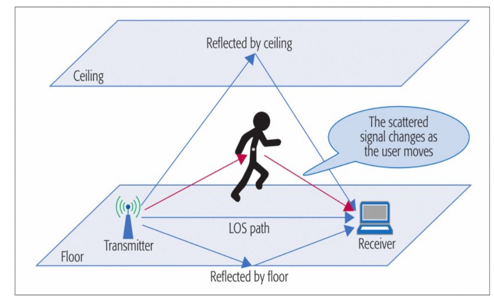
**Motion Capture Labs**

Restricted to contrived settings

**IMUs**

Not reliable due to drift issues



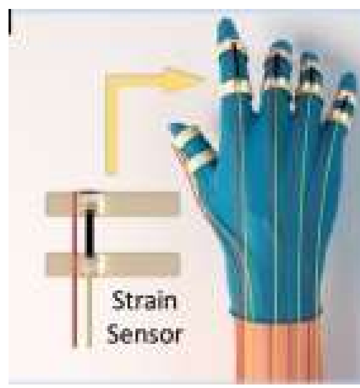




**Electromagnetics-Based**

Restricted and limited to activity classification


**Time of Flight**

Line of sight issues




**Bending Sensors**

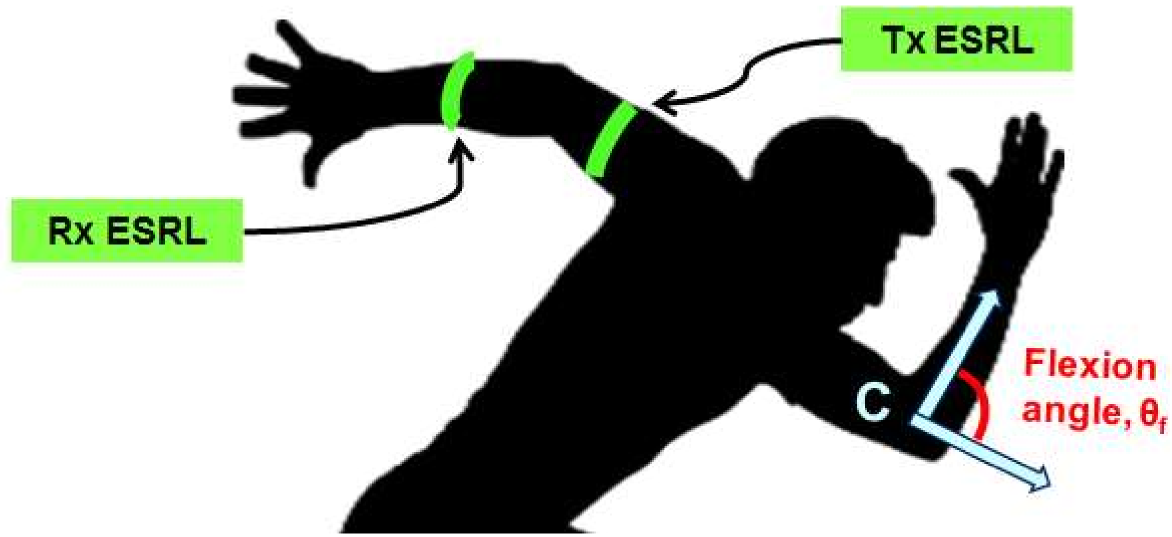
Restrict natural motion and limited by number of cycles of use.

[1] PC: Takeuchi et al., “Web-based avatar represented lecture viewer toward interactive e-lecture performed by 3d avatar,” in 2015 IEEE Global Engineering Education Conference (EDUCON), Mar. 2015, pp. 283–286
[2] PC: Gonz´alez-Villanueva et al., “Design of a wearable sensing system for human motion monitoring in physical rehabilitation,” Sensors, vol. 13, no. 6, pp. 7735–7755, Jun. 2013.
[3] PC: Wang et al.,, “Wi-fi CSI-based behavior recognition: From signals and actions to activities,” IEEE Communications Magazine, vol. 56, no. 5, pp. 109–115, May 2018.
[4] PC: Amendola et al., “Movement detection of human body segments: Passive radio-frequency identification and machine-learning technologies.” IEEE Antennas and Propagation Magazine, vol. 57, no. 3, pp. 23–37, Jun. 2015.
[5] Y. Qi, C. B. Soh, E. Gunawan, K.-S. Low, and A. Maskooki, “A novel approach to joint flexion/extension angles measurement based on wearable UWB radios,” IEEE Journal of Biomedical and Health Informatics, vol. 18, no. 1, pp. 300–308, Jan. 2014.
[6] C. Li, Y.-L. Cui, G.-L. Tian, Y. Shu, X.-F. Wang, H. Tian, Y. Yang, F. Wei, and T.-L. Ren, “Flexible CNT-array double helices strain sensor with high stretchability for motion capture,” Scientific Reports, vol. 5, no. 1, pp. 1–8, Nov. 2015

# Loop-Based Textile Kinematics Sensors Developed in our Group

## Advantages

- Real-time
- Non-contrived settings
- Seamless
- Unobtrusive
- Unrestricted natural movement
- Robust
- Reliable
- Injury Safe




ESRL: Electrically Small Resonant Loop (ESRL)

V. Mishra and A. Kiourti, "Wrap-Around Wearable Coils for Seamless Monitoring of Joint Flexion," *IEEE Transactions on Biomedical Engineering*, vol. 66, no. 10, pp. 2753–2760, Oct. 2019

V. Mishra and A. Kiourti, "Wearable Electrically Small Loop Antennas for Monitoring Joint Flexion and Rotation," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 1, pp. 134-141, Jan. 2020

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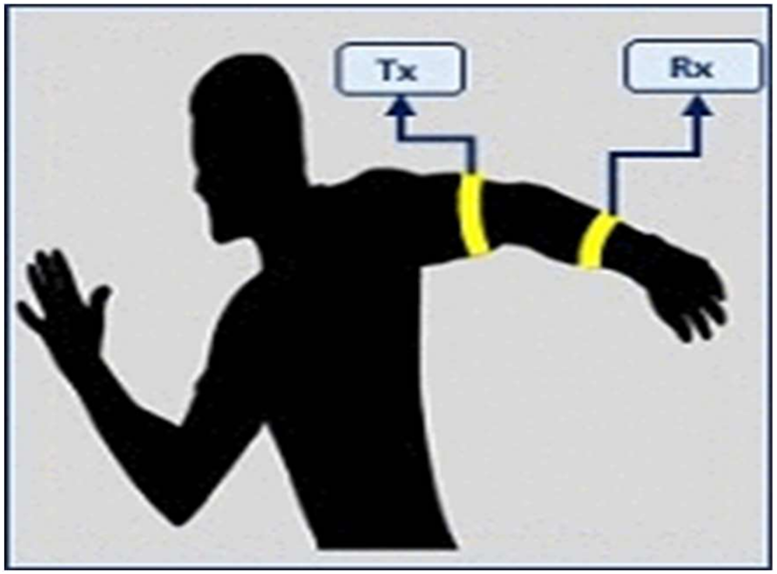
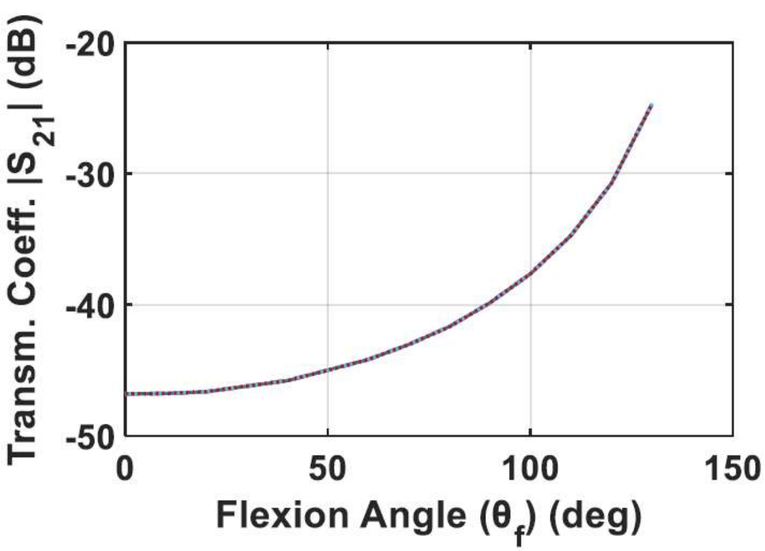
# Operating Principle of E-Textile Kinematic Sensors




Joint Flexion

↓

Loops misalign

↓

Value of $\boldsymbol{B_{Tx}}$ and angle between $\boldsymbol{B_{Tx}}$ and $\widehat{\boldsymbol{n_{Rx}}}$ changes

↓

Causes change in induced voltage

↓

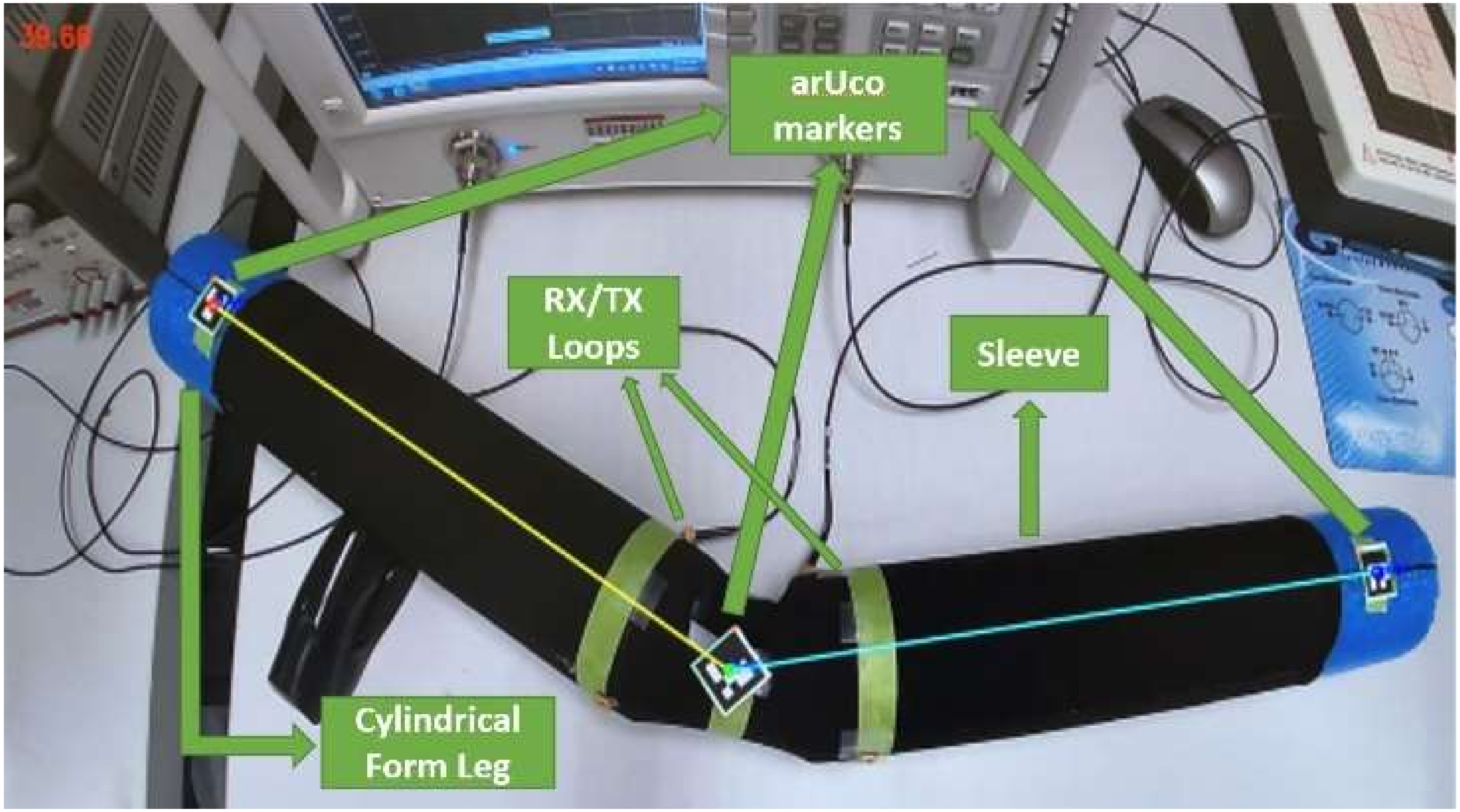
Used to monitor joint flexion/rotation

$$V_{Rx} = -\frac{d}{dt}\iint \boldsymbol{B_{Tx}} \,.\, \widehat{\boldsymbol{n_{Rx}}}\, ds$$

(Faraday's Law of Induction)

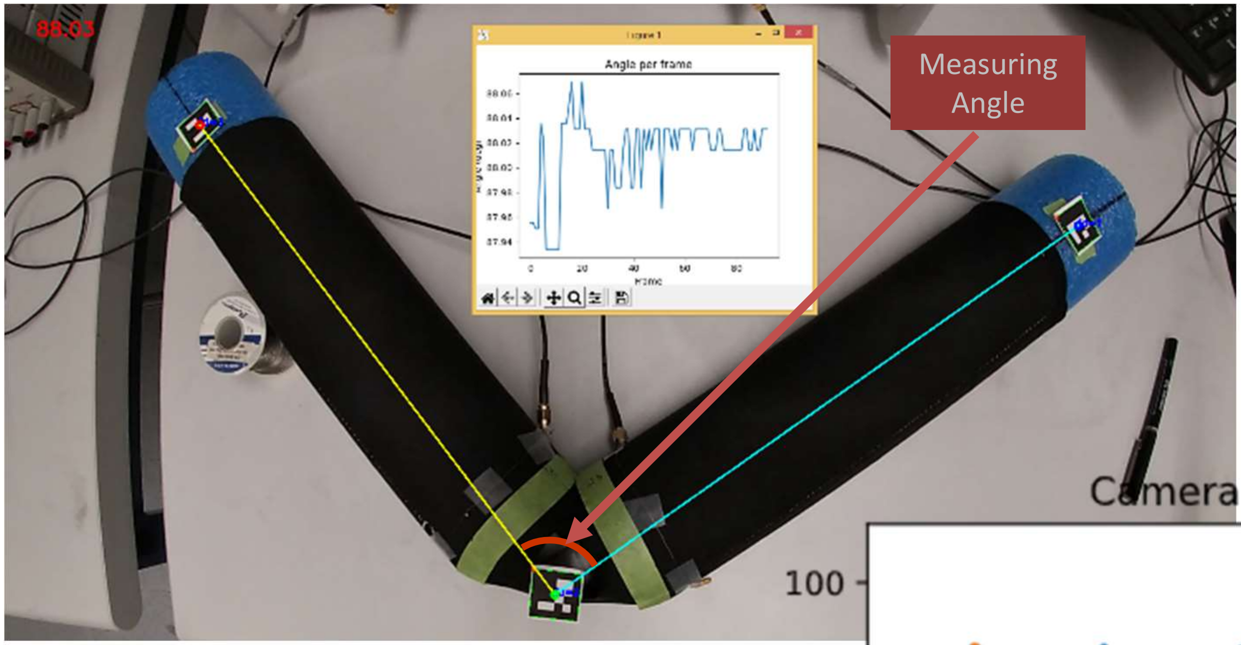
Mishra et al., "Wrap-Around Wearable Coils for Seamless Monitoring of Joint Flexion," *IEEE Trans. on Biomed. Eng.*, vol. 66, no. 10, pp. 2753-2760, Oct. 2019.

# Experimental Setup

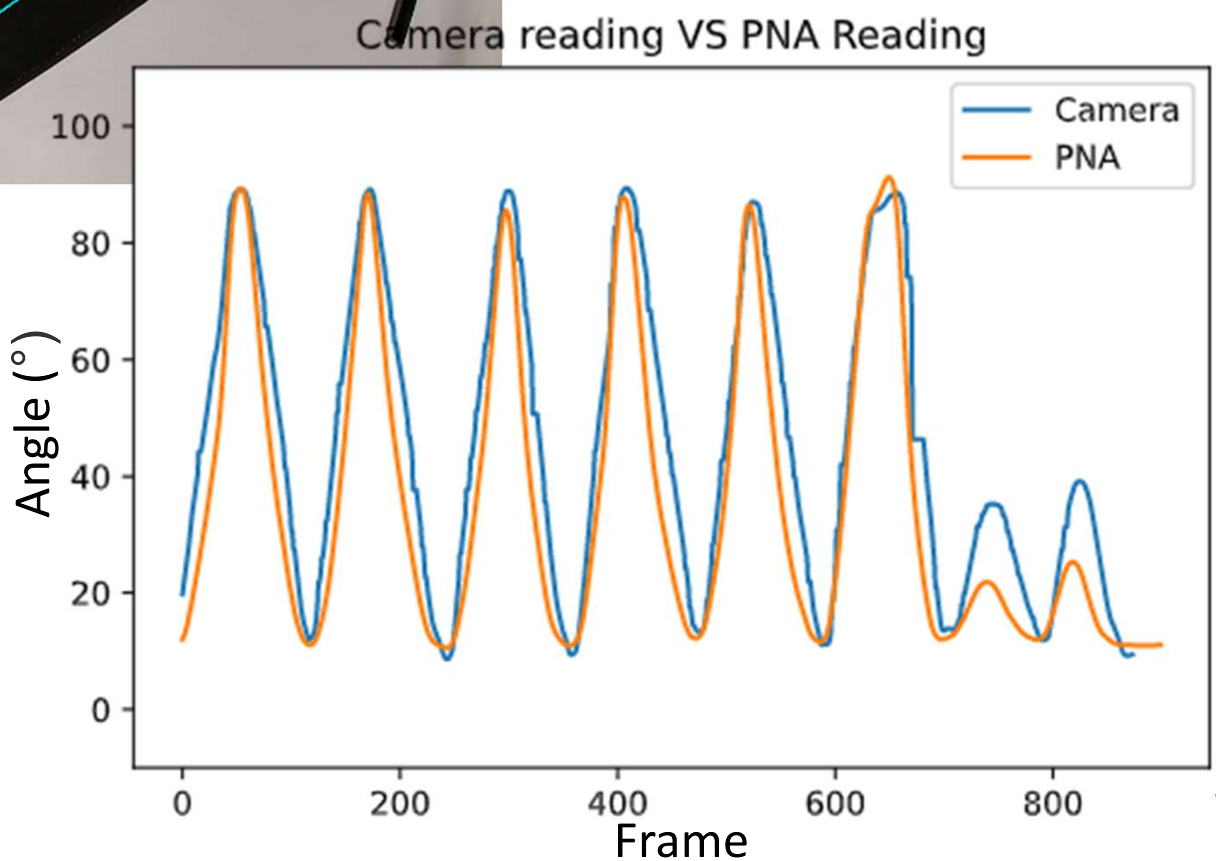



- Rotatable Styrofoam leg with loops on stretchy fit sleeve
- ArUco markers & computer vision for “gold standard” joint angle measurements
- Network analyzer for $|S_{21}|$ readings

# Data Collection Sample




Dynamic measurement of angle vs. time/frame



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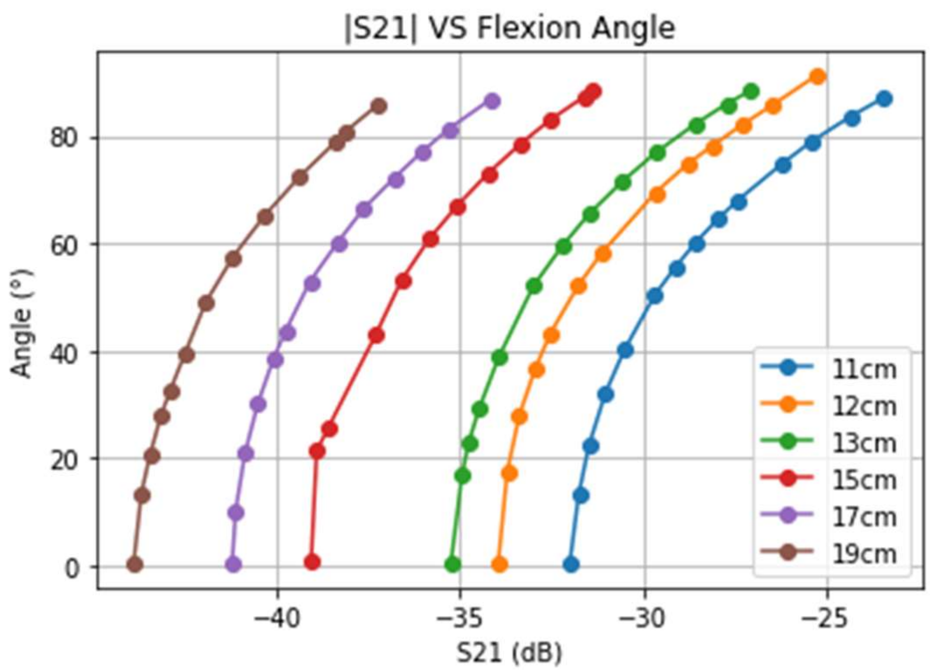
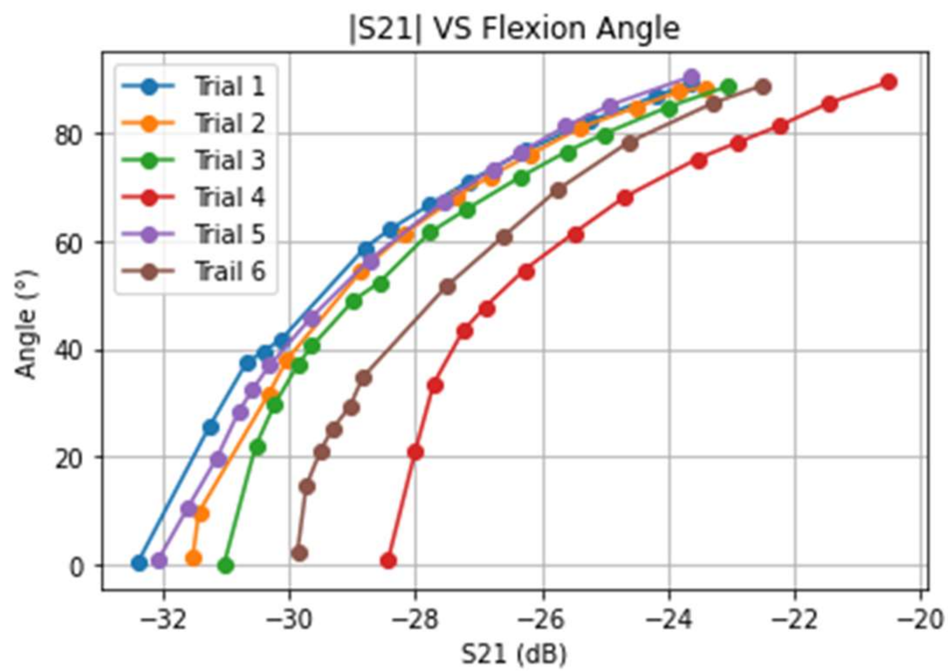
# Fabric Drift Error: Measurement Observations



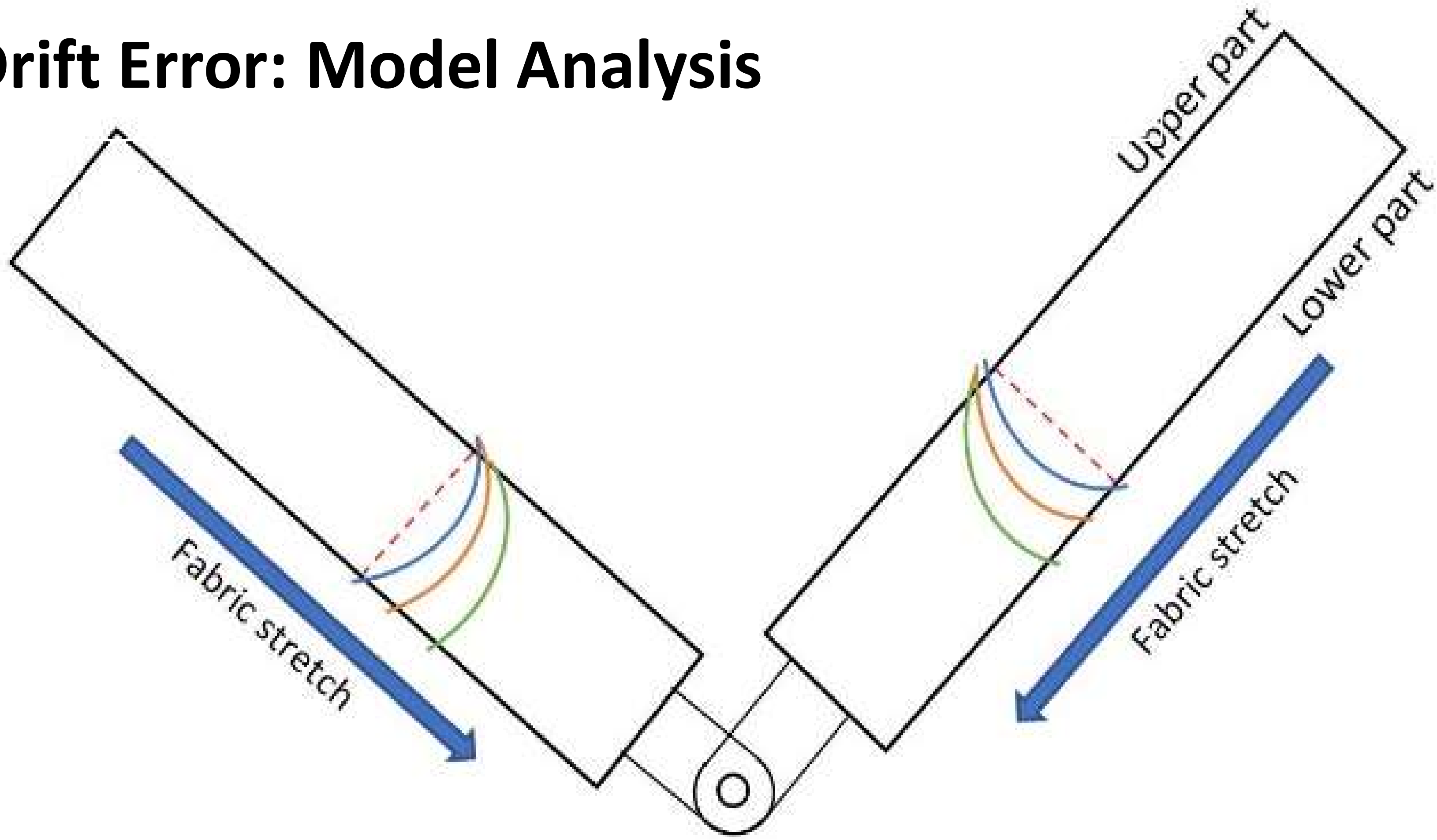

**$|S_{21}|$ VS Angle WITHOUT considering sleeve stretches**

- Predictable
- Curvature hardly changes under different conditions
- Can shift left/right based on $|S_{21}|$ at 0°

**$|S_{21}|$ VS Angle WITH considering sleeve stretches**

- Hard to predict
- Curvature changes significantly under different condition
- Cannot just shift left/right

# Fabric Drift Error: Model Analysis




**Fabric stretches unevenly with joint flexion, causing the loops' relative position to change over time.**

**How can we calibrate out this error?**

- Introduction
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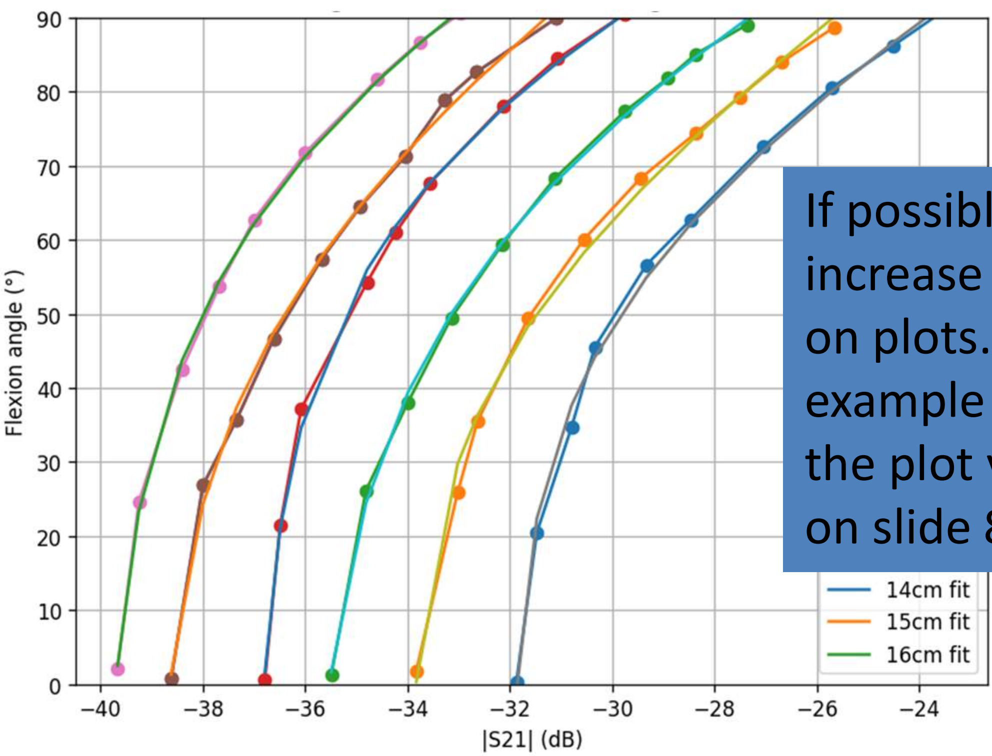
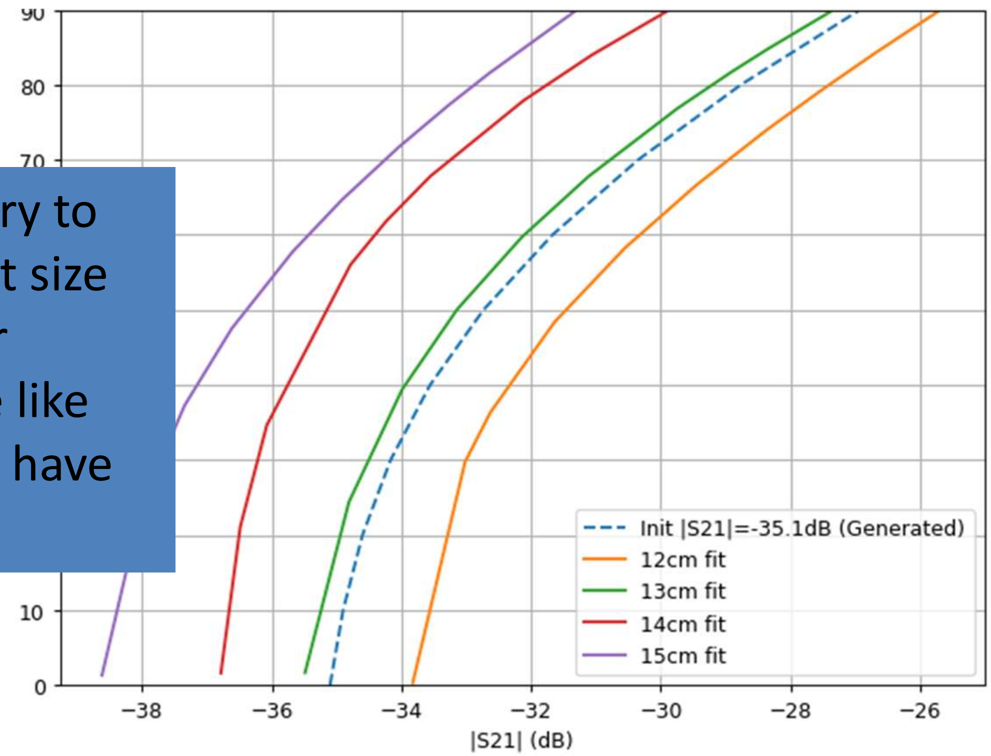
# STEP 1: Initial Condition Calibration



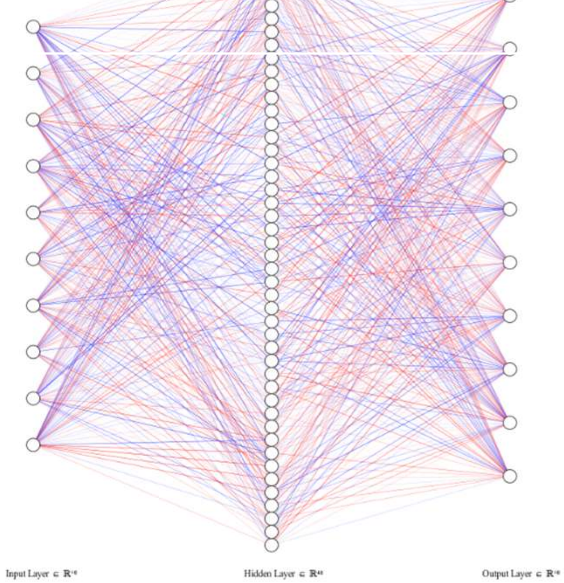

If possible, try to increase font size on plots. For example the like the plot you have on slide 8

**Collect $|S_{21}|$ VS Angle w/o considering sleeve stretches → convert into logarithmic equation**

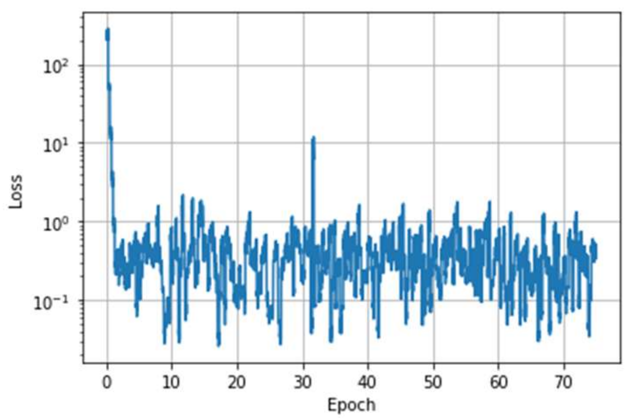
**Generate $|S_{21}|$ VS Angle curves <u>w/o considering sleeve stretches</u> based on their $|S_{21}|$ value @ 0° (initial condition)**

$$\hat{y} = a \cdot log_{10}x + b \cdot x + d$$

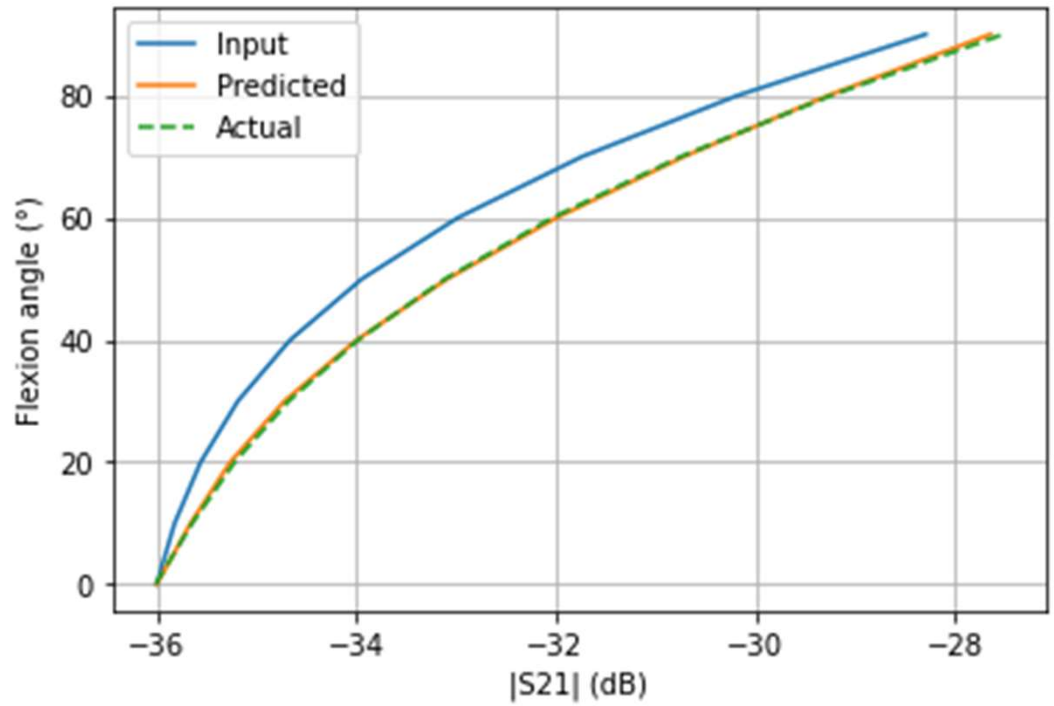
# STEP 2: Machine Learning Aided Calibration



10 nodes for input and output (10 data points of $|S_{21}|$ VS Flexion Angle curve), 48 nodes for hidden layer




Test loss after 300 epochs
(2000 data samples), lr=0.005




Using trained network to get calibrated $|S_{21}|$ VS Flexion Angle curve at a specific initial condition (-36dB @ 0°).

**Error after calibration ≤ 0.3°**

Input = $|S_{21}|$ VS Flexion Angle w/o sleeve
Predicted = $|S_{21}|$ VS Flexion Angle w/ sleeve

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- **Conclusion**
  - Fabric **drift can be detrimental in the operation of loop-based textile kinematics sensors**
  - **Proposed 2-step methodology can calibrate out this error**
  - **Preliminary results show errors below 0.5°**
- **Future Work**
  - **Adapt to dynamic motion measurements (i.e., joint flexing during sensor sampling)**
  - **Improve accuracy**

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# Thank you!

# Questions?

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