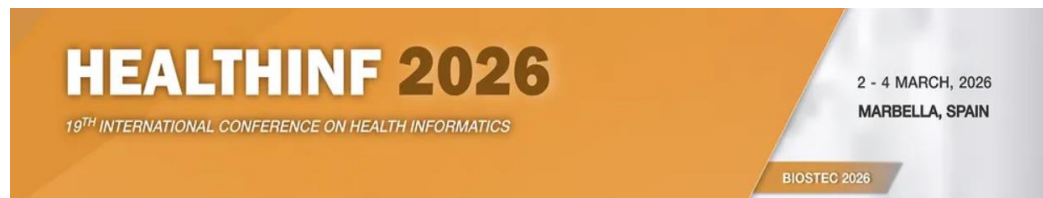


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# A Comprehensive Infrastructure and Methodology for Multi-Modal Data Acquisition to Empower AI-based Rehabilitation

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Presented by

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# Limitations Affecting Real-World AI Rehabilitation Systems

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**Why do AI-based rehabilitation systems struggle transitioning from research environments to clinical practice?**

- ✓ Unstable sensor synchronization
- ✓ Drift and anatomical misalignment
- ✓ Inconsistent exercise labeling
- ✓ Poor dataset reproducibility

***Reliable AI requires reliable, synchronized and anatomically consistent data.***

# Bridging Accuracy and Real-World Deployability

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## Optical Systems

- High spatiotemporal precision
- Laboratory controlled environment
- Limited scalability for home use



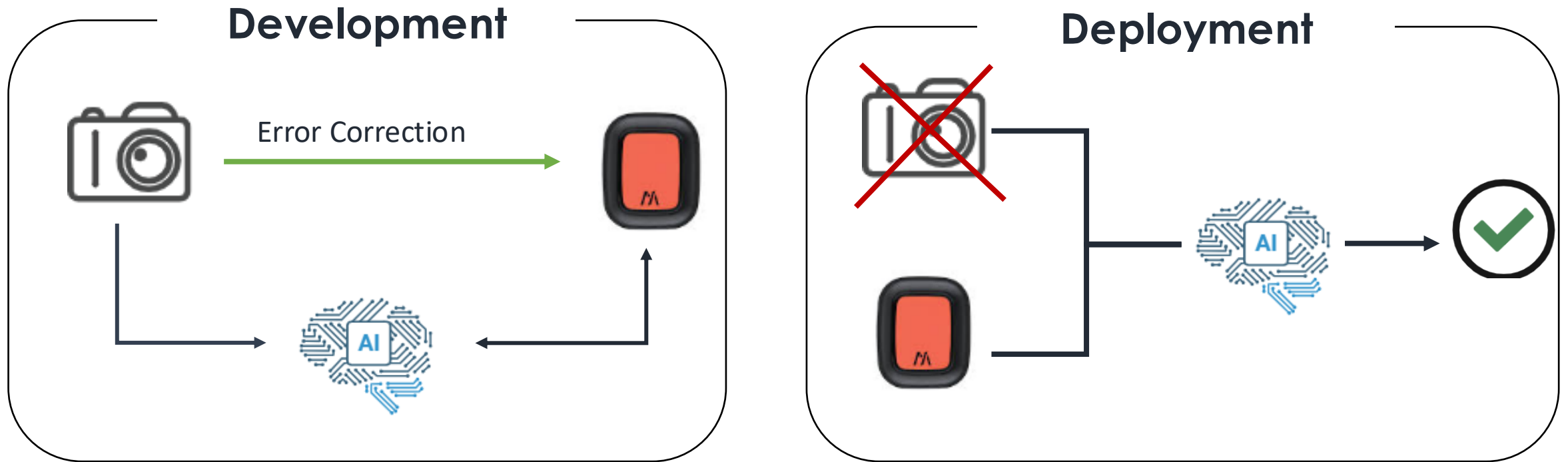
## Wearable sensors (IMUs)

- Real world deployable sensing
- Cost effective and portable
- Susceptive to drift and alignment errors



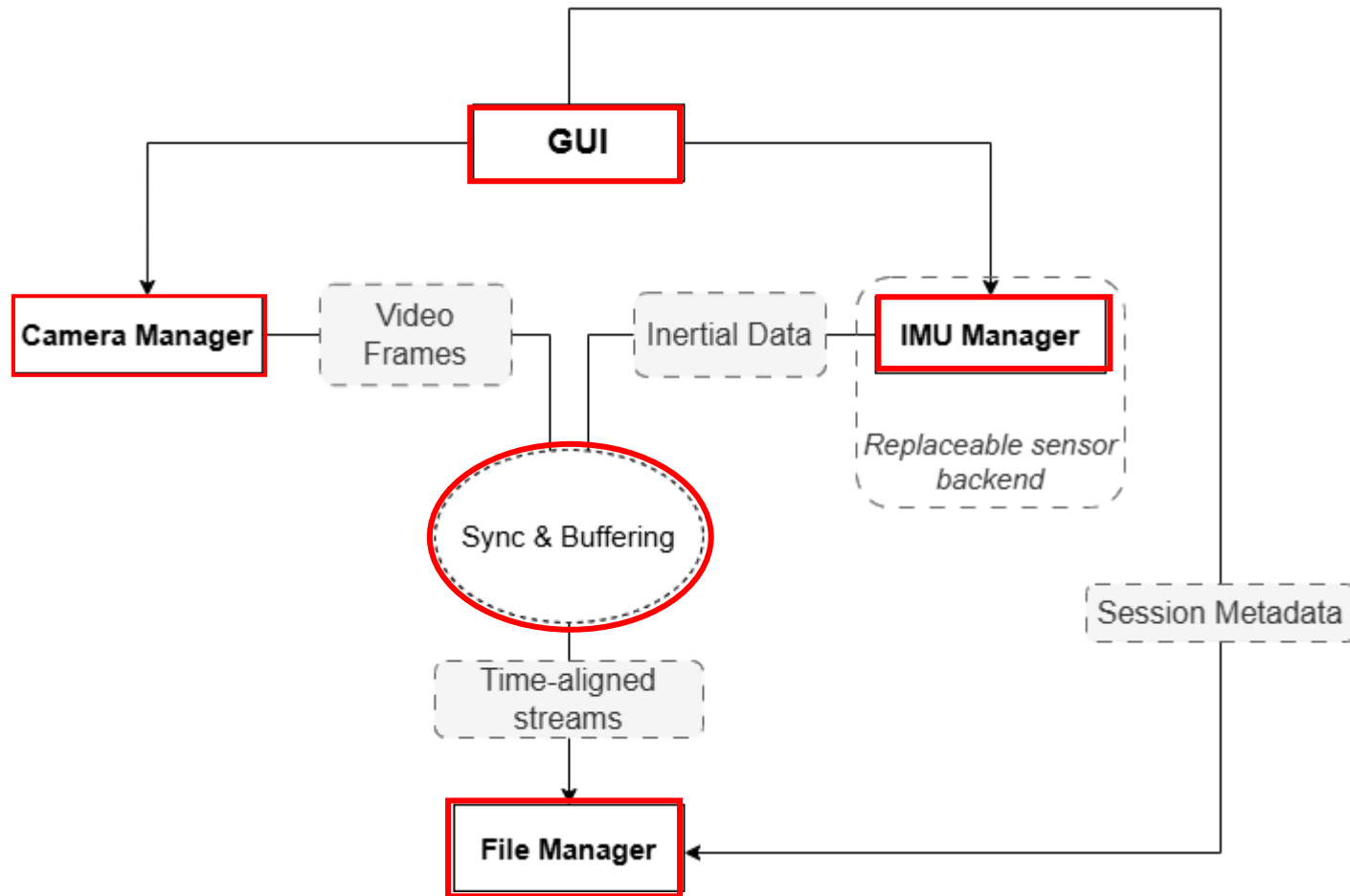
**Multimodal synchronization bridges accuracy and scalability**

# From Multimodal Supervision to Sensor-Only Development



Multi-modal data collection is the bridge to reliable AI models for unsupervised recovery.

# Recording Studio – System Architecture



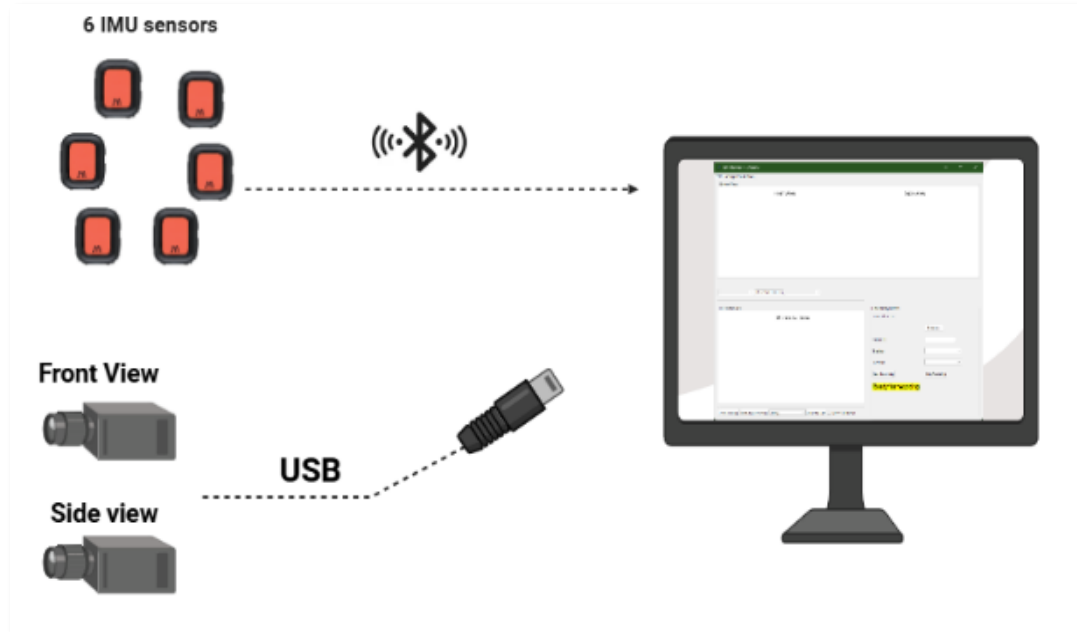
✓ **Centralized Control Layer**  
GUI-based configuration and session management

✓ **Concurrent Multi-stream Acquisition**  
Event driven concurrent multi-stream acquisition

✓ **Time aligned Dataset generation**  
Buffered synchronization before storage

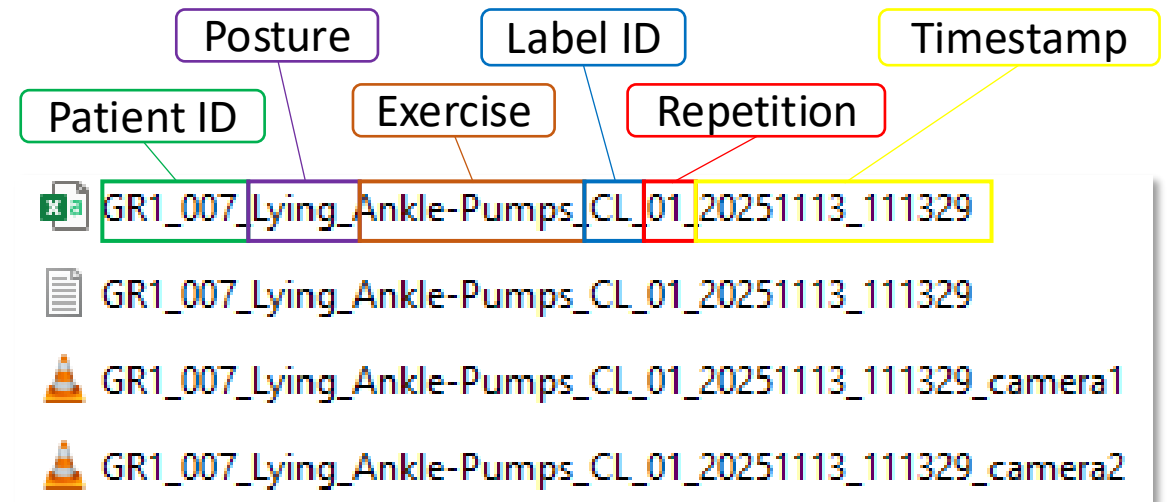
✓ **Replaceable Sensor Backend**  
IMU Manager can be adapted to different wearable devices

# Recording Studio - Multimodal Recording and Data Export



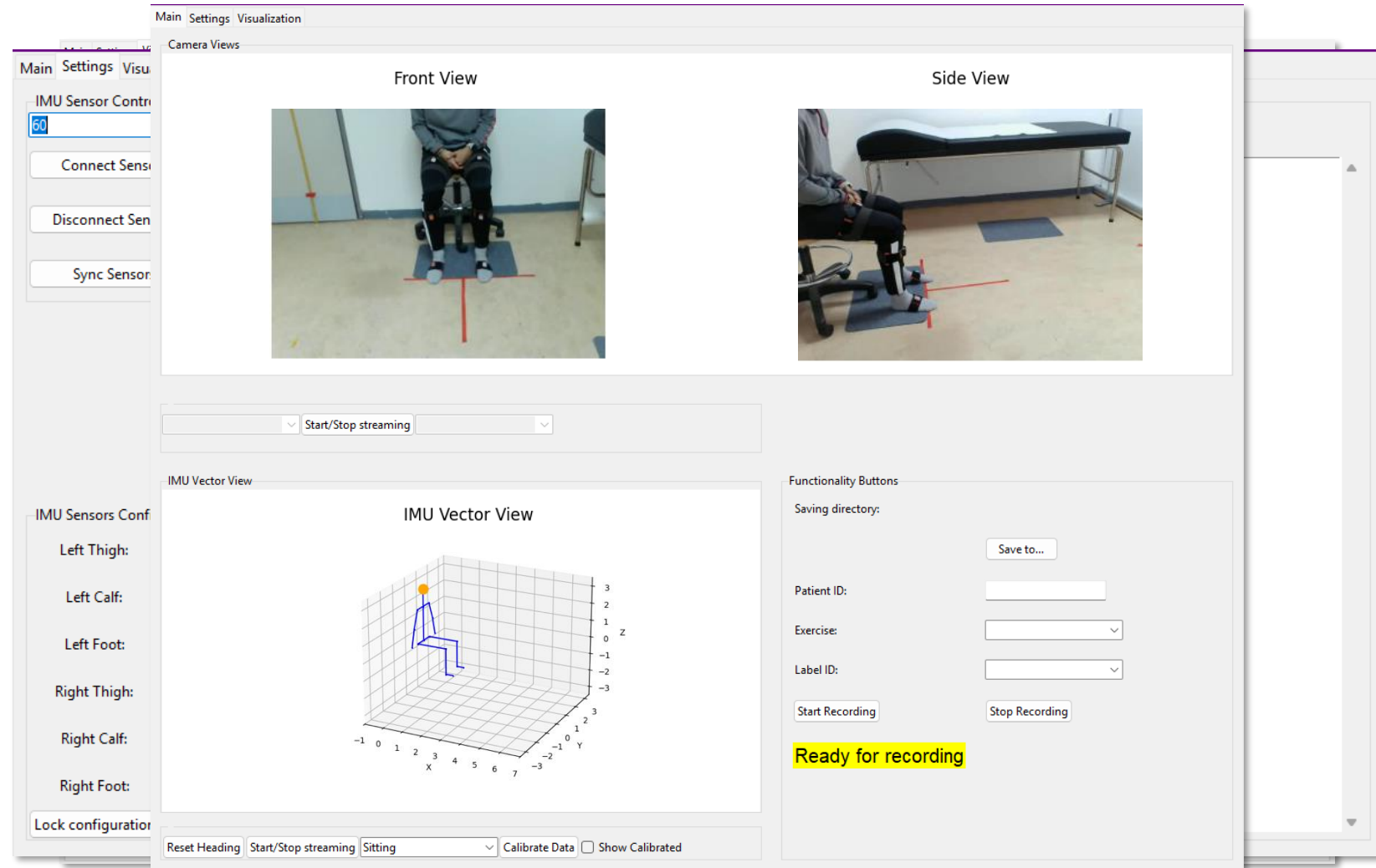
- Six Movella DOTs concurrent BLE streaming with synchronized inertial timestamps.
- Frontal and lateral optical recording for multimodal supervision.

- Frame - rate alignment:  
30 Hz inertial sampling & 30 fps video capture.
- Structured dataset export:  
IMU data (.csv and .txt format) and  
dual-camera recordings (.mp4 format)

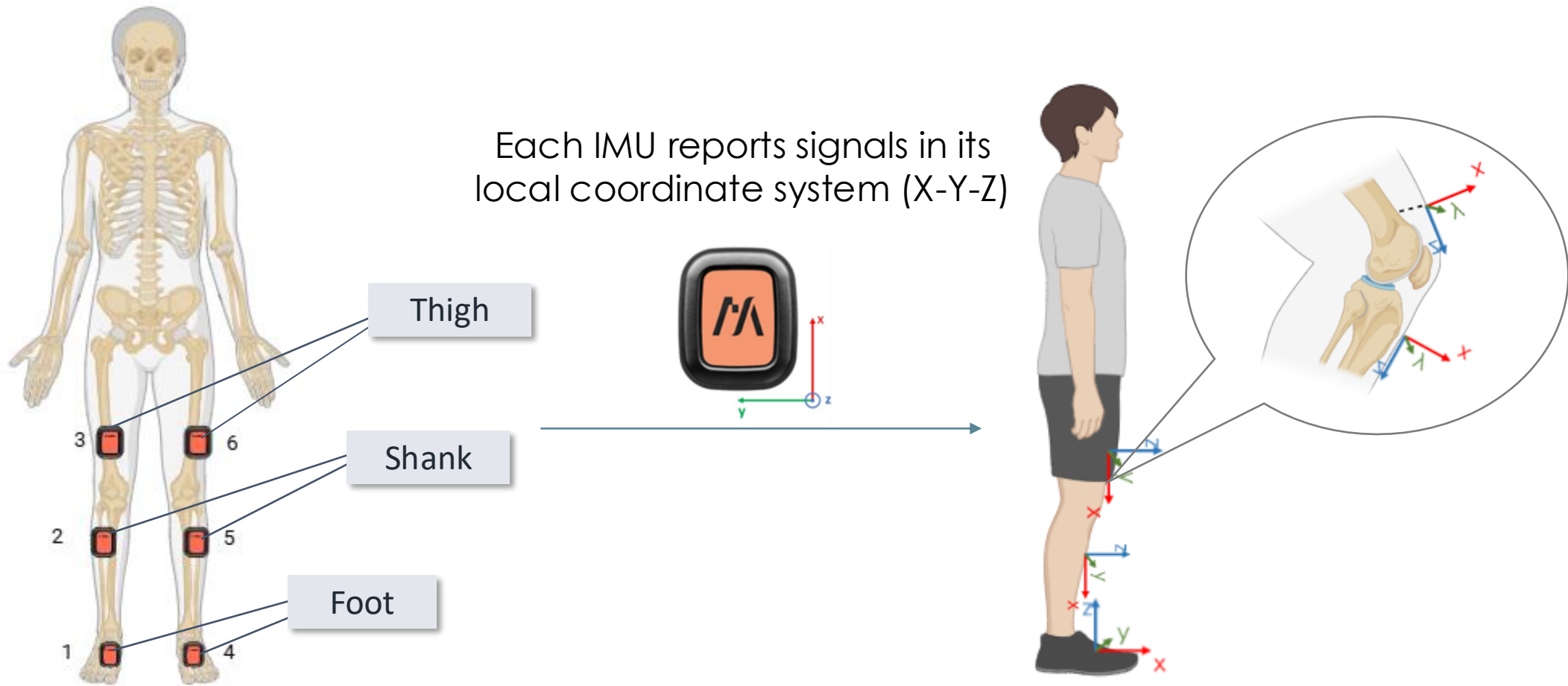


# Integrated Control and Visualization Environment

Visualization  
Main Tab



# Sensor Placement and Coordinate System Mapping

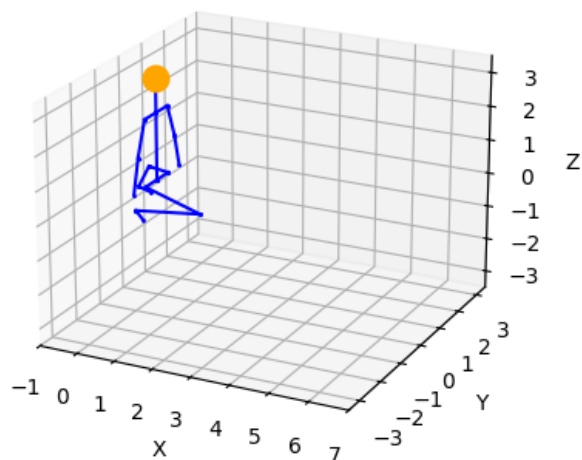


Reliable kinematic estimation requires consistent sensor-to-segment alignment across all local coordinate systems.

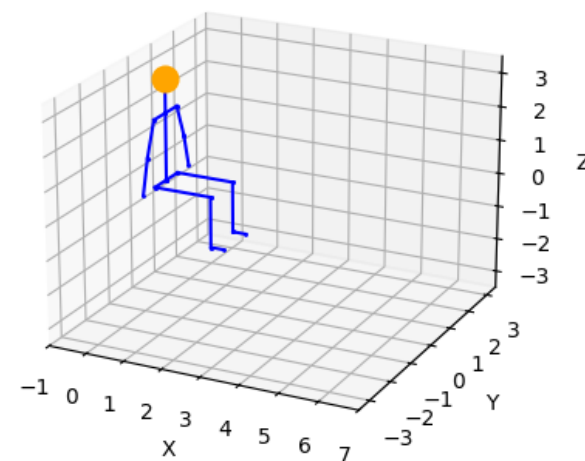


# Static calibration for Anatomically Consistent 3D Pose

*Before (Uncalibrated)*



*After (Calibrated)*



$$q' = q_{calib}^{-1} * q$$

**Static Calibration:** aligns local sensor frames to anatomical segment references through quaternion normalization.

# Temporal Consistency Across Six IMUs

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$33.4 \pm 0.5$  ms

Mean sampling interval  
 $N \approx 6,000$

$<0.004\%$

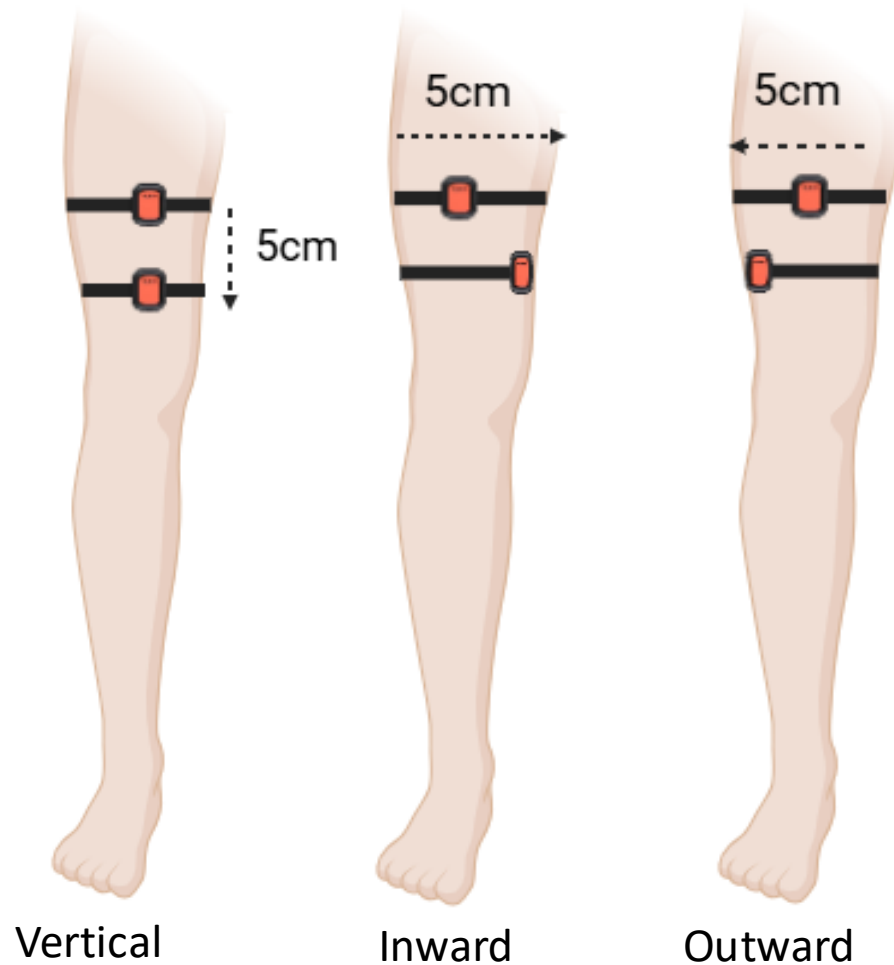
Packet Loss

$29.9 \pm 0.2$  Hz

Experimental Frame Rate  
(Target: 30Hz)

Stable concurrent BLE streaming under multimodal acquisition conditions.

# Impact of Sensor Misplacement on Acceleration



## Vertical Misplacement (5cm) ↓

**RMSE X:**  $0.045 \pm 0.025$  g (*static gravitational component*)

**RMSE Y:**  $0.039 \pm 0.020$  g

**RMSE Z:**  $0.10 \pm 0.06$  g

**PAE Z:** 0.2608 g

## Inward Lateral Misplacement (5cm) ←

**RMSE X:**  $0.104 \pm 0.083$  g

**RMSE Y:**  $0.0055 \pm 0.090$  g

**RMSE Z:**  $0.243 \pm 0.307$  g

**PAE Z:** 0.938 g

## Outward Lateral Misplacement (5cm) →

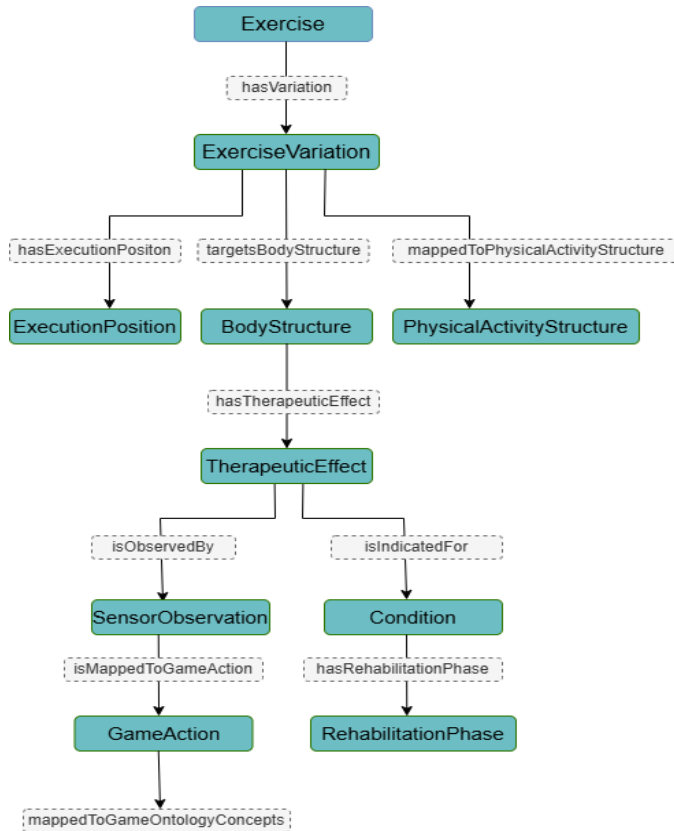
**RMSE X:**  $0.0735 \pm 0.057$  g

**RMSE Y:**  $0.079 \pm 0.148$  g

**RMSE Z:**  $0.131 \pm 0.140$  g

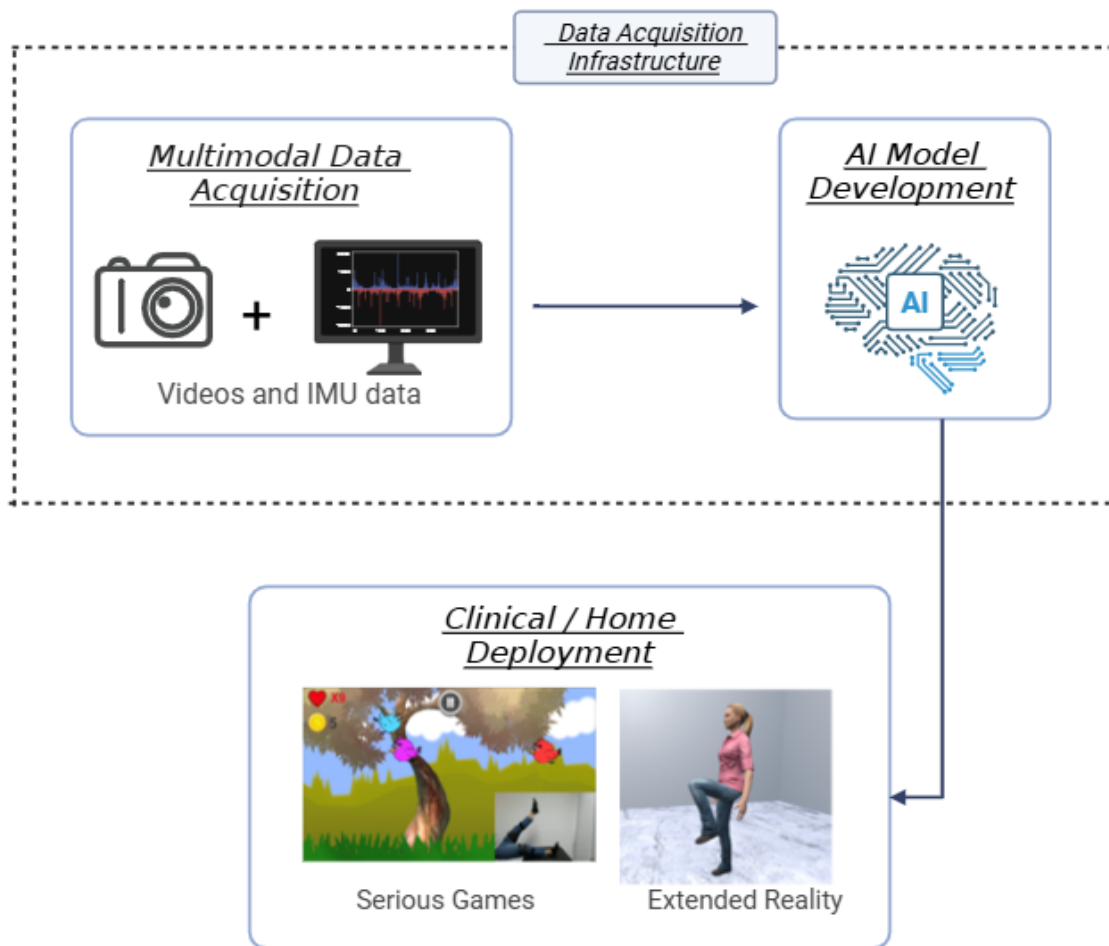
**PAE Z:** 0.505 g

# Towards an Ontology based Data Structuring



- ✓ Formal definition of exercises and variations.
- ✓ Explicit mapping of anatomical segments and sensor positions.
- ✓ Structured linkage between segment movements and game actions.
- ✓ Alignment with clinical standards (e.g., PACO, ICF, SNOMED CT, ICD-11).

# Towards an AI-Enabled Deployment



- ✓ Cross-modal synchronization validation
- ✓ Annotation & labeling
- ✓ AI model development for exercise classification

*"The proposed infrastructure serves as the foundation for scalable, AI-enabled rehabilitation systems."*



# Thank you!

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 ThrombUS<sup>+</sup>

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