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the European Union

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02/12/2021

Faculteit Industriële Ingenieurswetenschappen  
Campus Brugge | Campus De Nayer | Sint-Katelijne-Waver | Campus Diepenbeek  
Campus Geel | Campus Groep T Leuven | Campussen Gent en Aalst

KU LEUVEN

# Contactless Multi-sensor Solution to Support Physiotherapy

08/06/2023

BIOSINT Meeting

Jona Cappelle

Interreg

France-Wallonie-Vlaanderen



UNION EUROPÉENNE  
EUROPESE UNIE

NOMADe



AVEC LE SOUTIEN DU FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL  
MET STEUN VAN HET EUROPEES FONDS VOOR REGIONALE ONTWIKKELING

INTRODUCTION

POSSIBLE SOLUTIONS

RESULTING SYSTEM

CHALLENGES

CONCLUSION

# INTRODUCTION | WHAT?

Neuro-musculoskeletal conditions

Revalidation + kinesitherapy

Insights in neuro-musculoskeletal conditions

Measure entropy of movement

Remote e-treatment



INTRODUCTION  
POSSIBLE SOLUTIONS  
RESULTING SYSTEM  
CHALLENGES  
CONCLUSION

# SOLUTIONS | MOTION TRACKING SYSTEMS

## Ultra-reliable real-time positioning

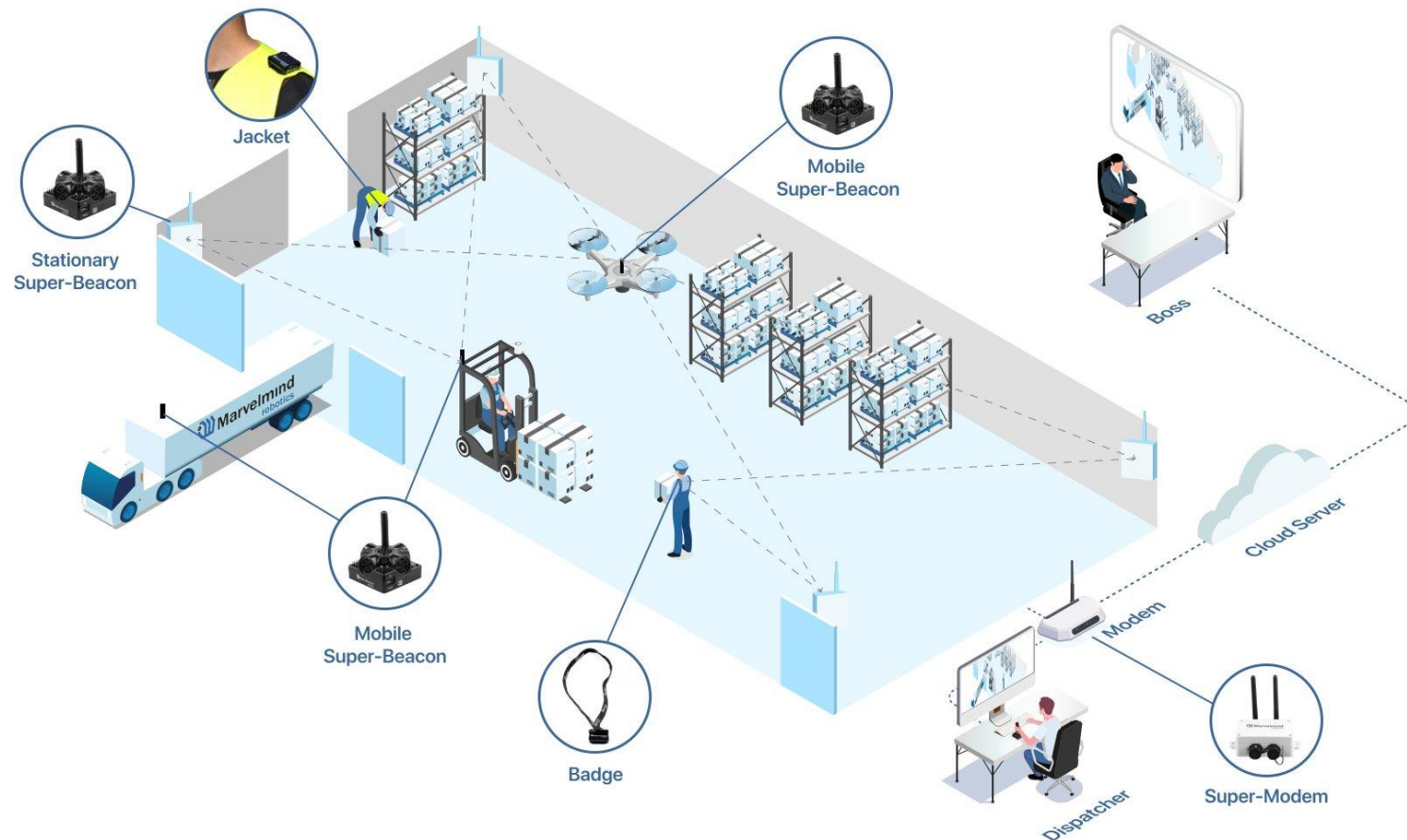
Ultra-wideband positioning solution with accuracy of 10 cm



# SOLUTIONS | MOTION TRACKING SYSTEMS

## Precise ( $\pm 2\text{cm}$ ) Indoor Positioning System

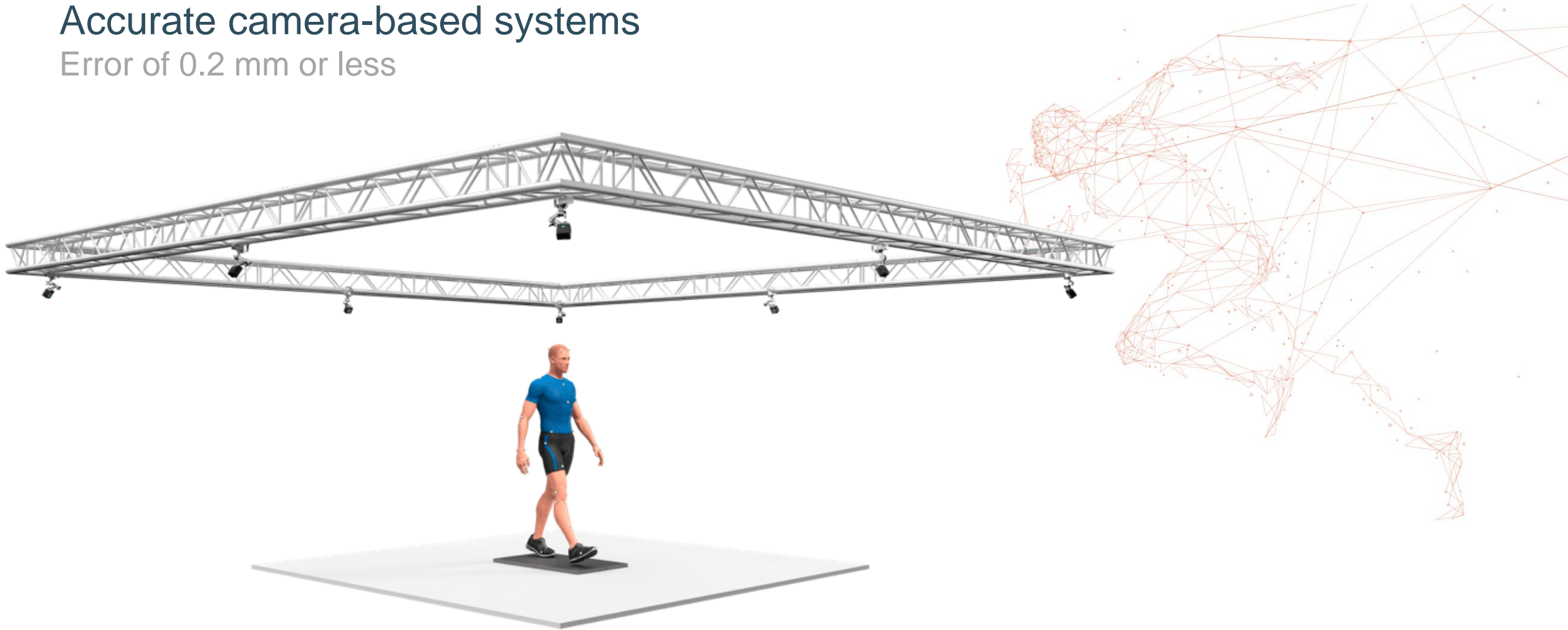
for autonomous robots, drones, vehicles and humans



# SOLUTIONS | MOTION TRACKING SYSTEMS

## Accurate camera-based systems

Error of 0.2 mm or less



**VICON**

**OptiTrack**

# SOLUTIONS | ON-BODY SENSORS

## Real-time full body motion capture system

IMU-based sensing system



INTRODUCTION  
POSSIBLE SOLUTIONS  
**RESULTING SYSTEM**  
CHALLENGES  
CONCLUSION

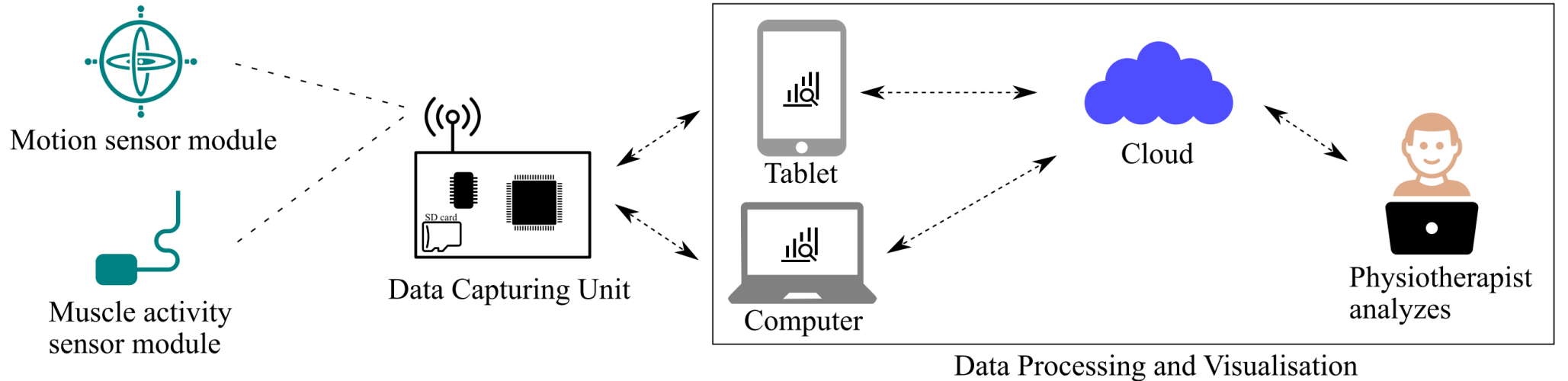
# SYSTEM | OVERVIEW

## Traditional visit

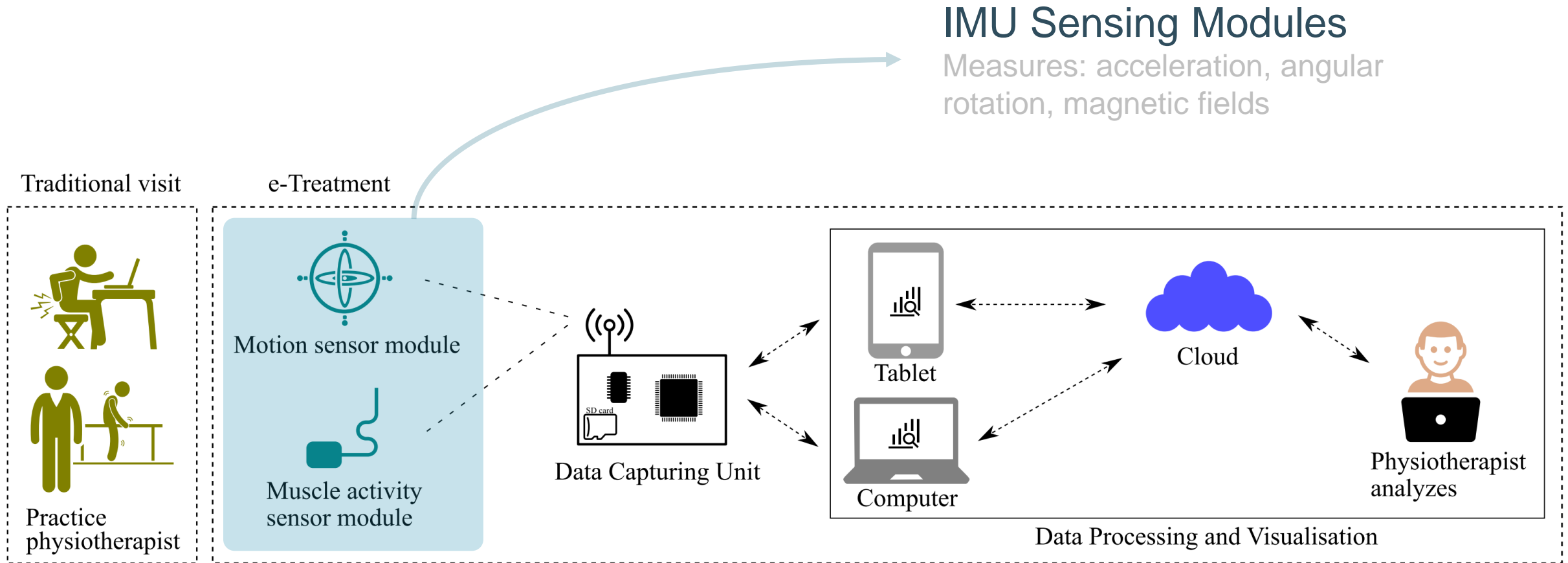


Practice  
physiotherapist

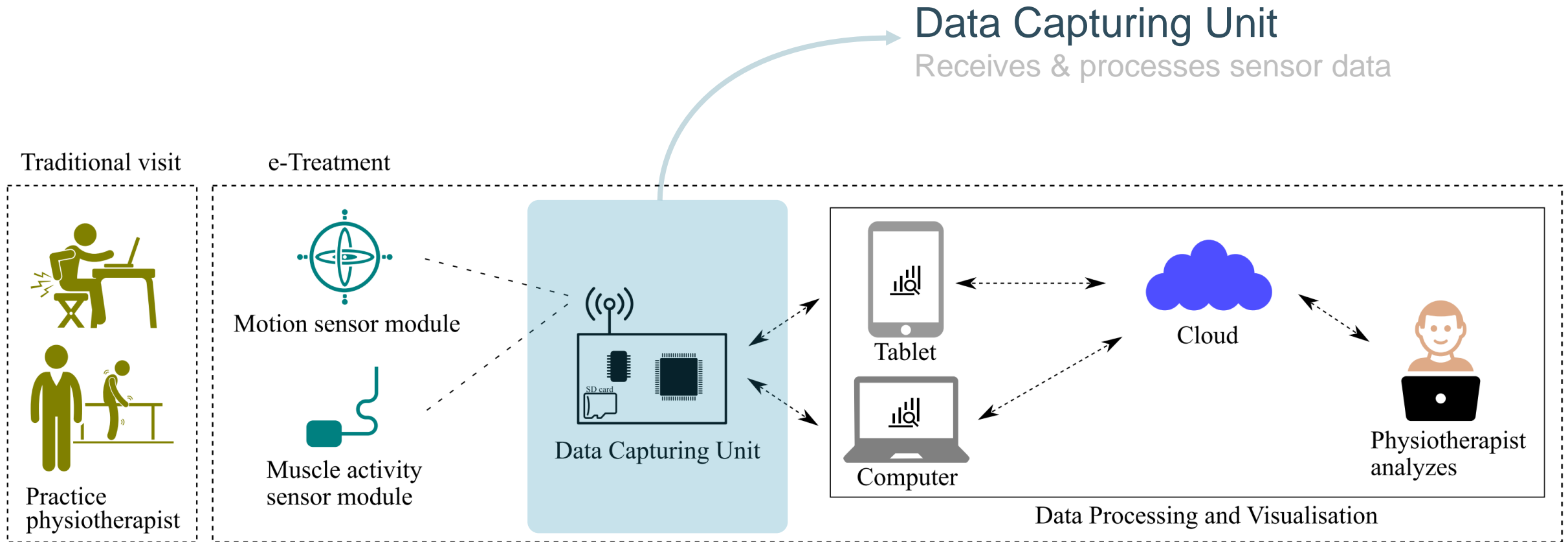
## e-Treatment



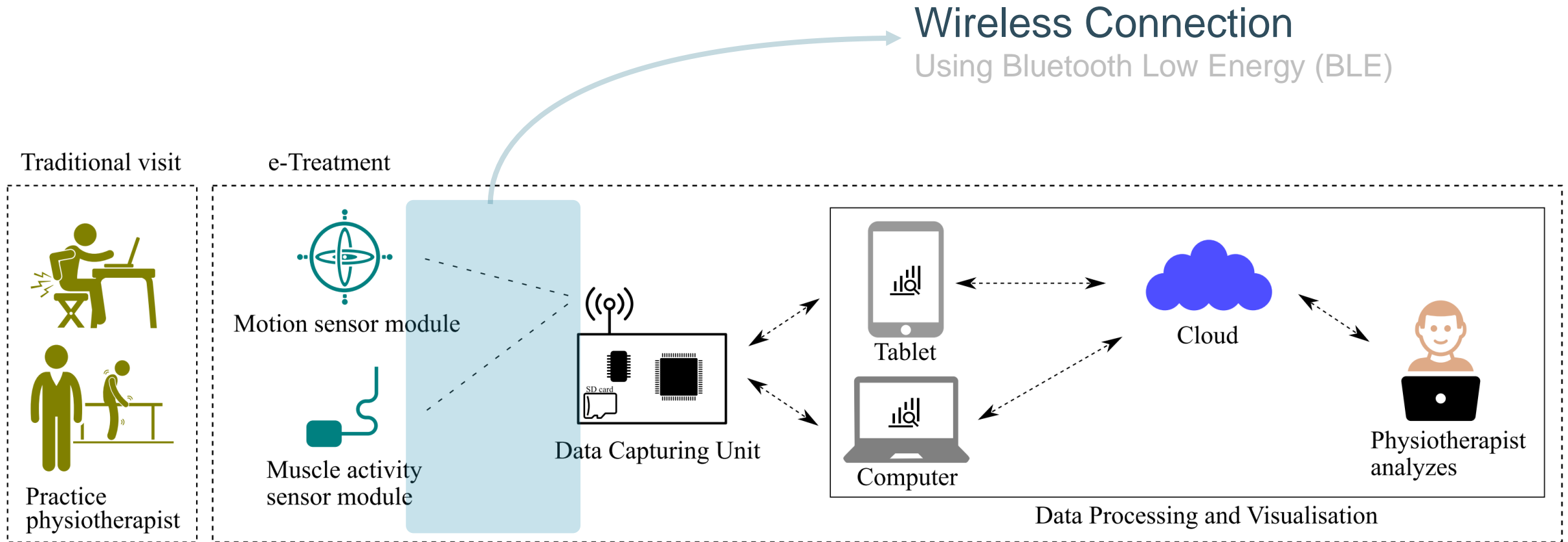
# SYSTEM | OVERVIEW



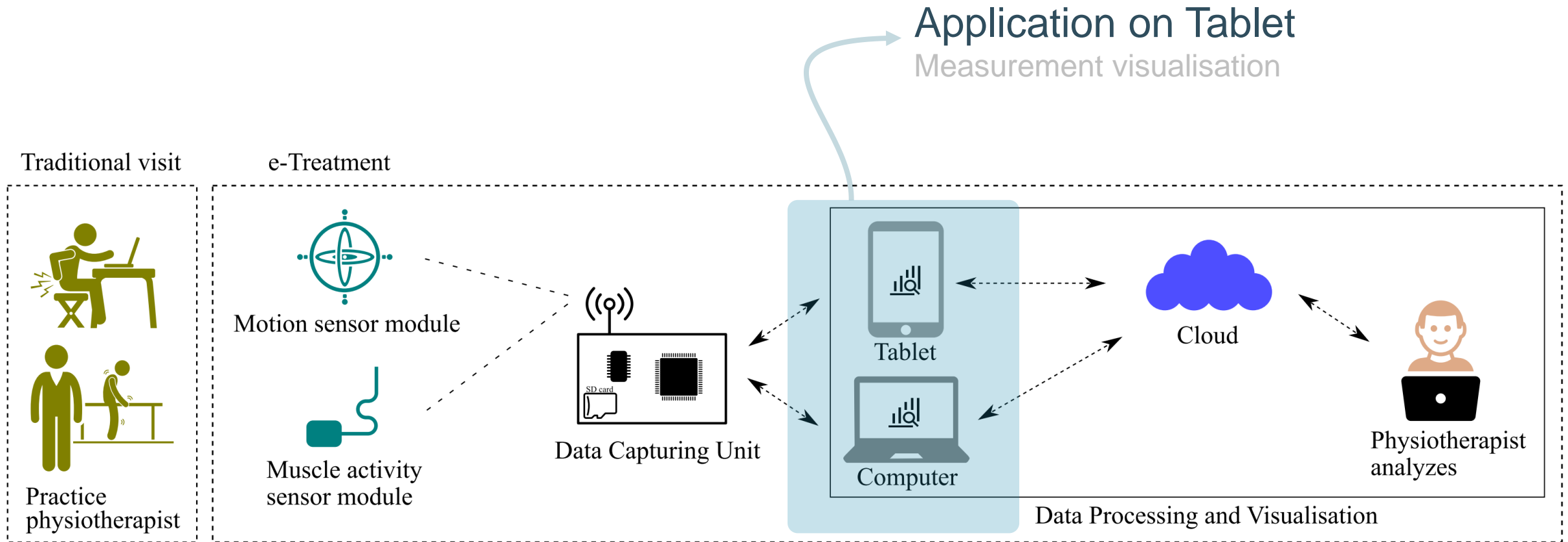
# SYSTEM | OVERVIEW



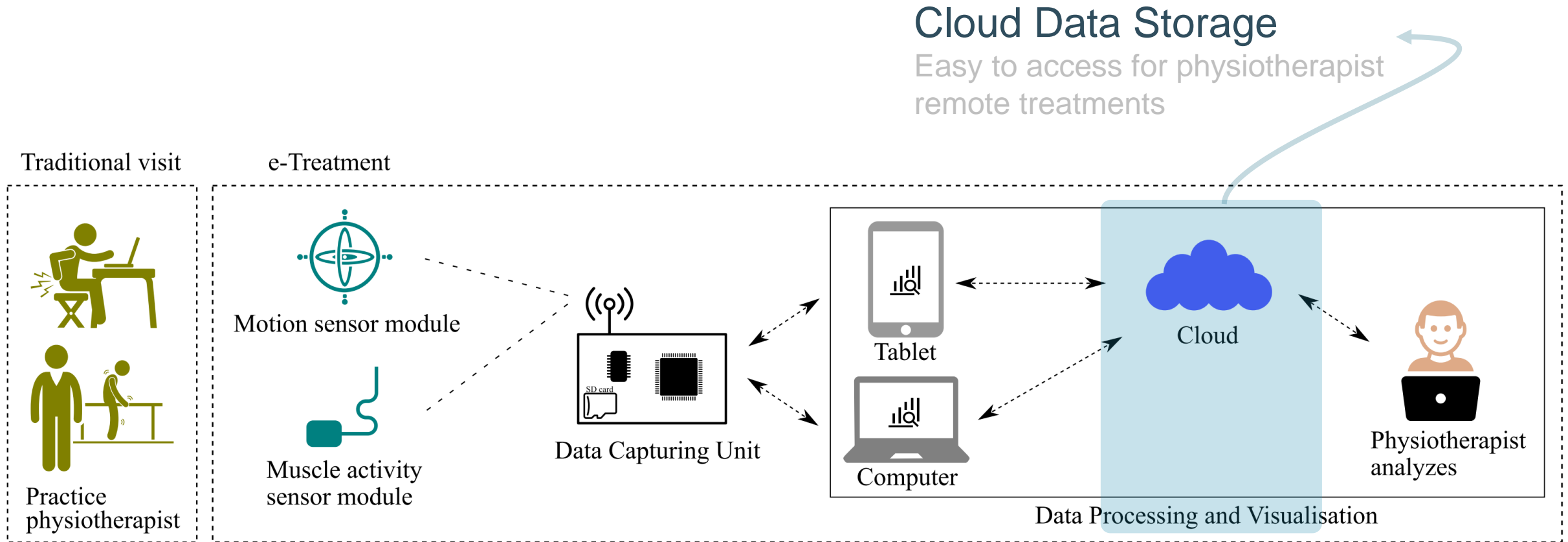
# SYSTEM | OVERVIEW



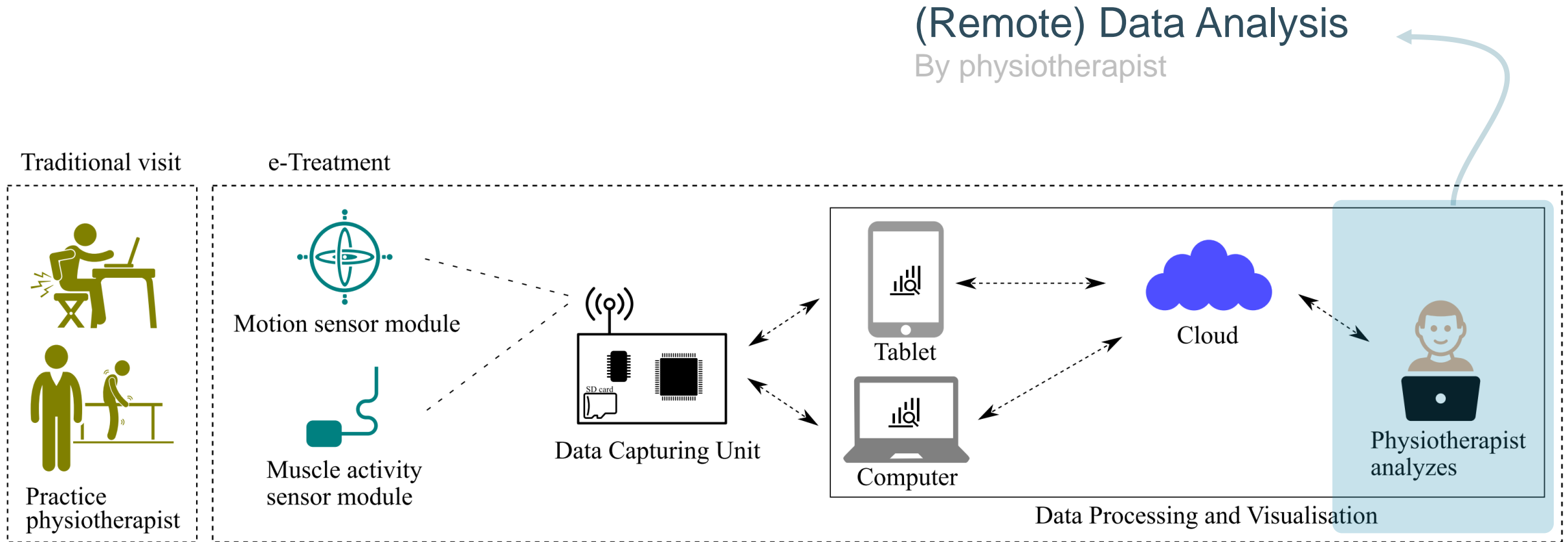
# SYSTEM | OVERVIEW



# SYSTEM | OVERVIEW



# SYSTEM | OVERVIEW



# SYSTEM | OVERVIEW



Motion sensors  
(IMUs)



Data Capturing Unit  
(DCU)

# SYSTEM | OVERVIEW

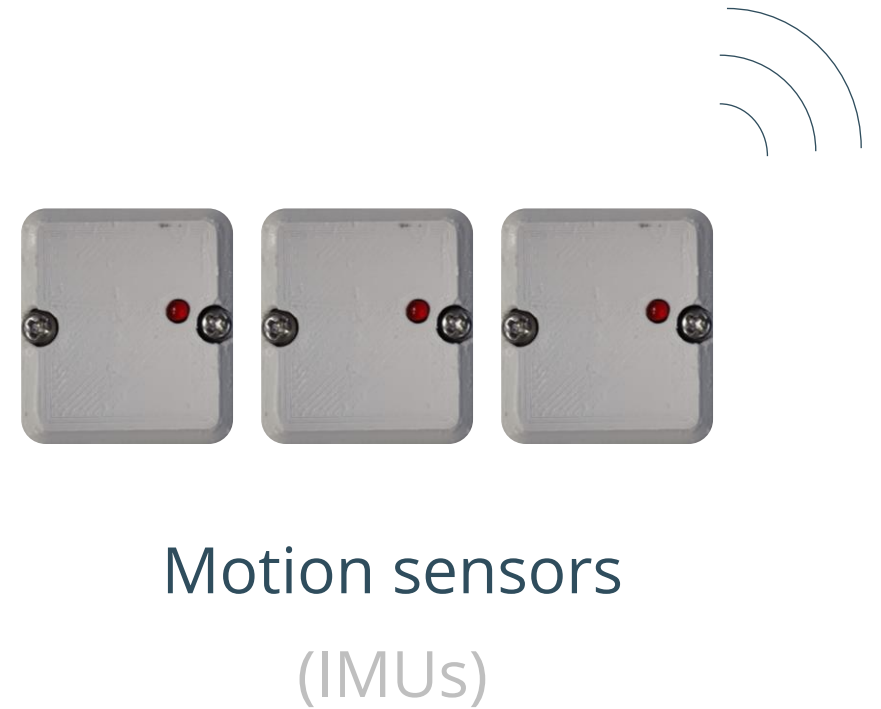
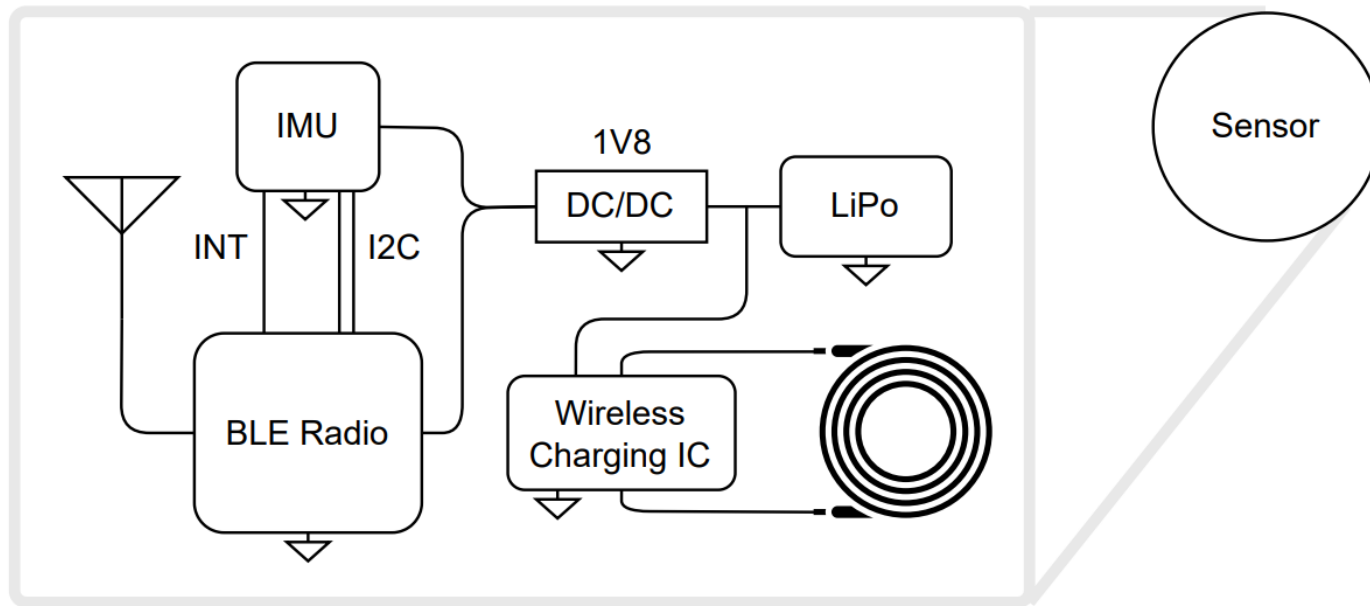


Motion sensors  
(IMUs)



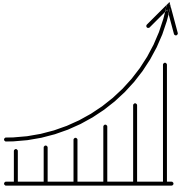
Data Capturing Unit  
(DCU)

# SYSTEM | SENSOR IN DETAIL



# SYSTEM | MEMS SENSORS

## Inertial Measurement Unit (IMU)



Higher performance compared to macroscale counterparts



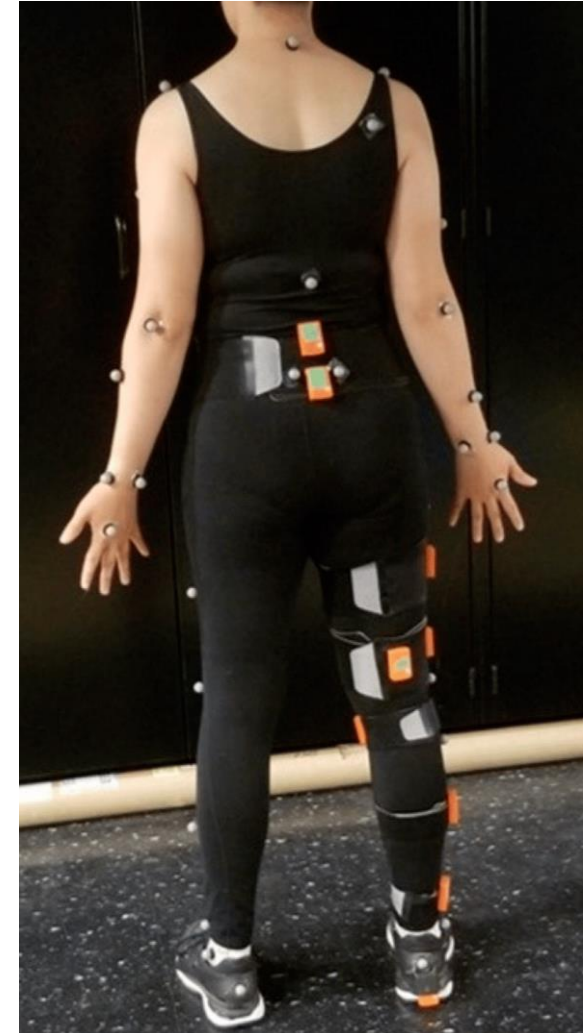
Low production cost per-device



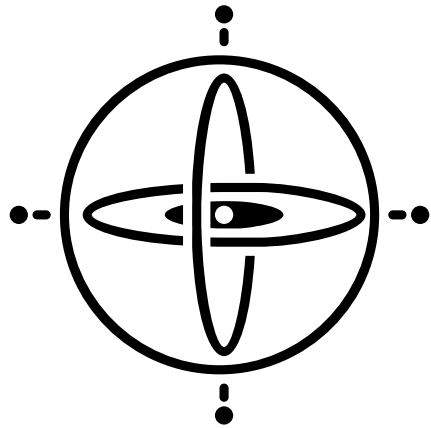
Similar functionality in smaller devices



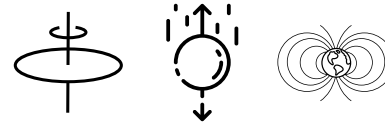
Potential: Minimized sensors, actuators together with IC on same silicon



# SOLUTIONS | PURPOSE OF IMU



Measures

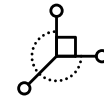


Angular velocity

Acceleration

Magnetic field

Orientation



Position estimation



# SOLUTIONS | PURPOSE OF IMU

Measures

Obtain raw data

Angular velocity



Gyroscope

Acceleration



Accelerometer

Magnetic field



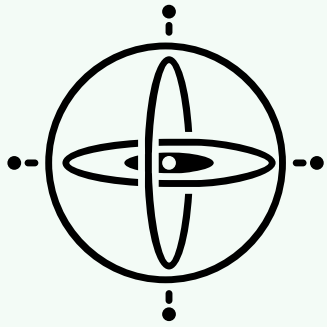
Magnetometer

Orientation

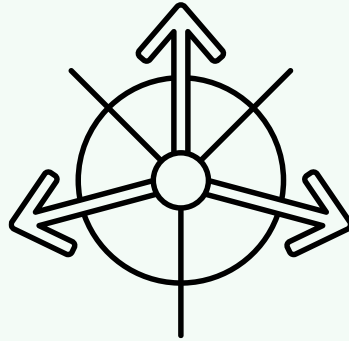
Position estimation



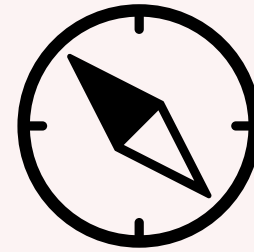
# SOLUTIONS | SENSOR TYPES



Gyroscope



Accelerometer



Magnetometer

6 Degrees of Freedom (DoF)

9 DoF

# SYSTEM | OVERVIEW



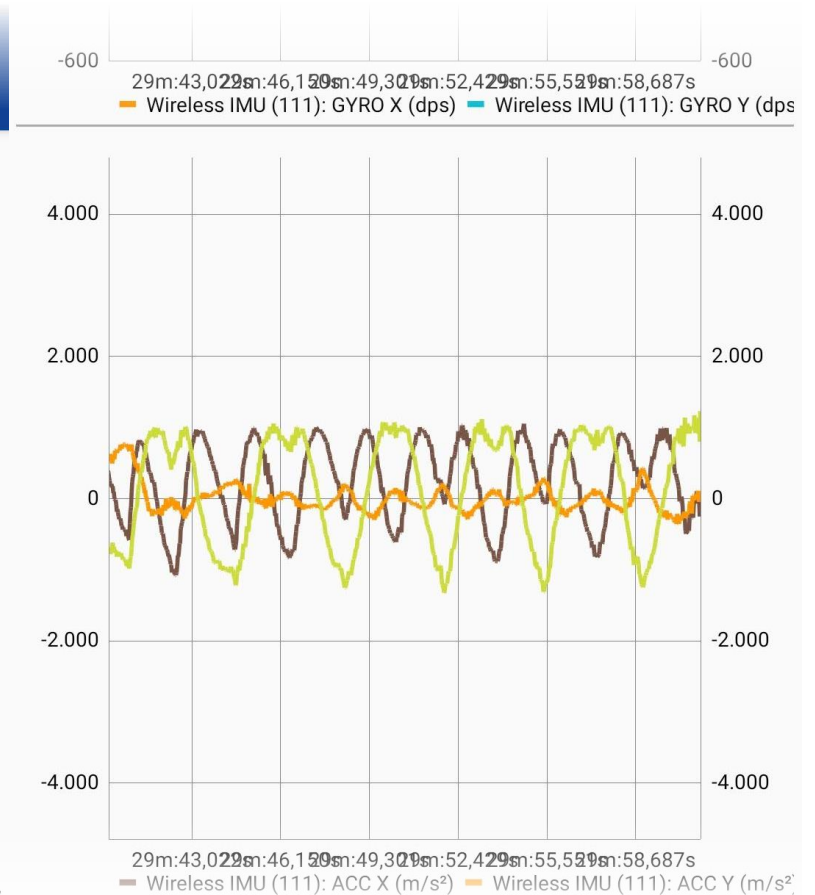
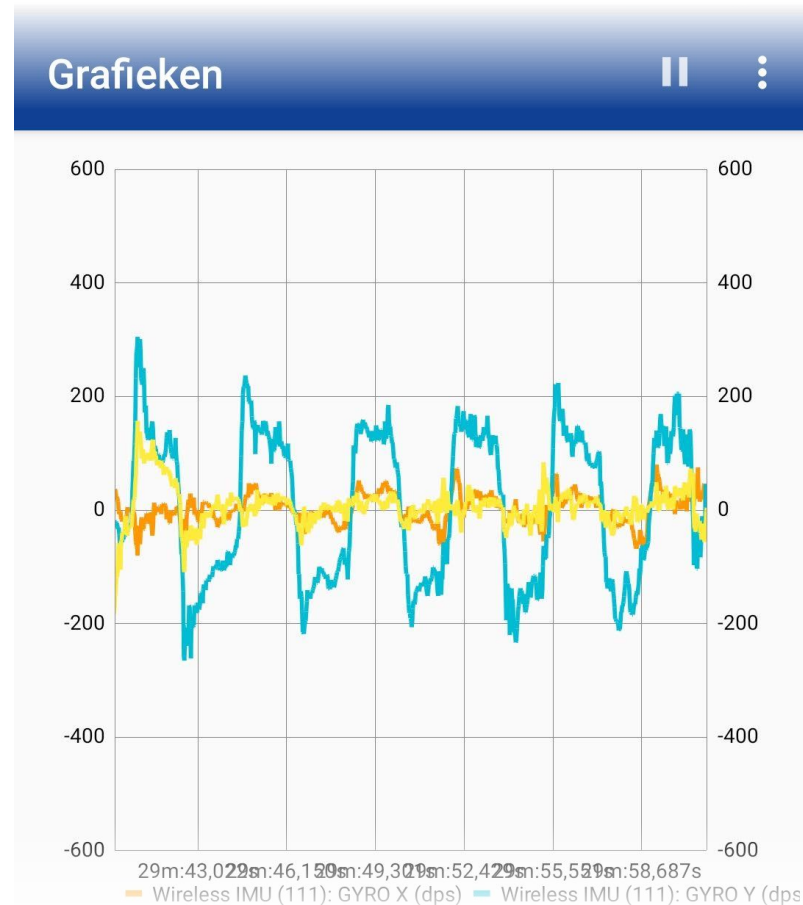
Motion sensors  
(IMUs)



Data Capturing Unit  
(DCU)

# SYSTEM | APP

- Multiple sensor real-time visualization
- Storage of measurements in database



# SYSTEM | FEATURES



Wake on Motion



Runtime Calibration



Persistent Calibration

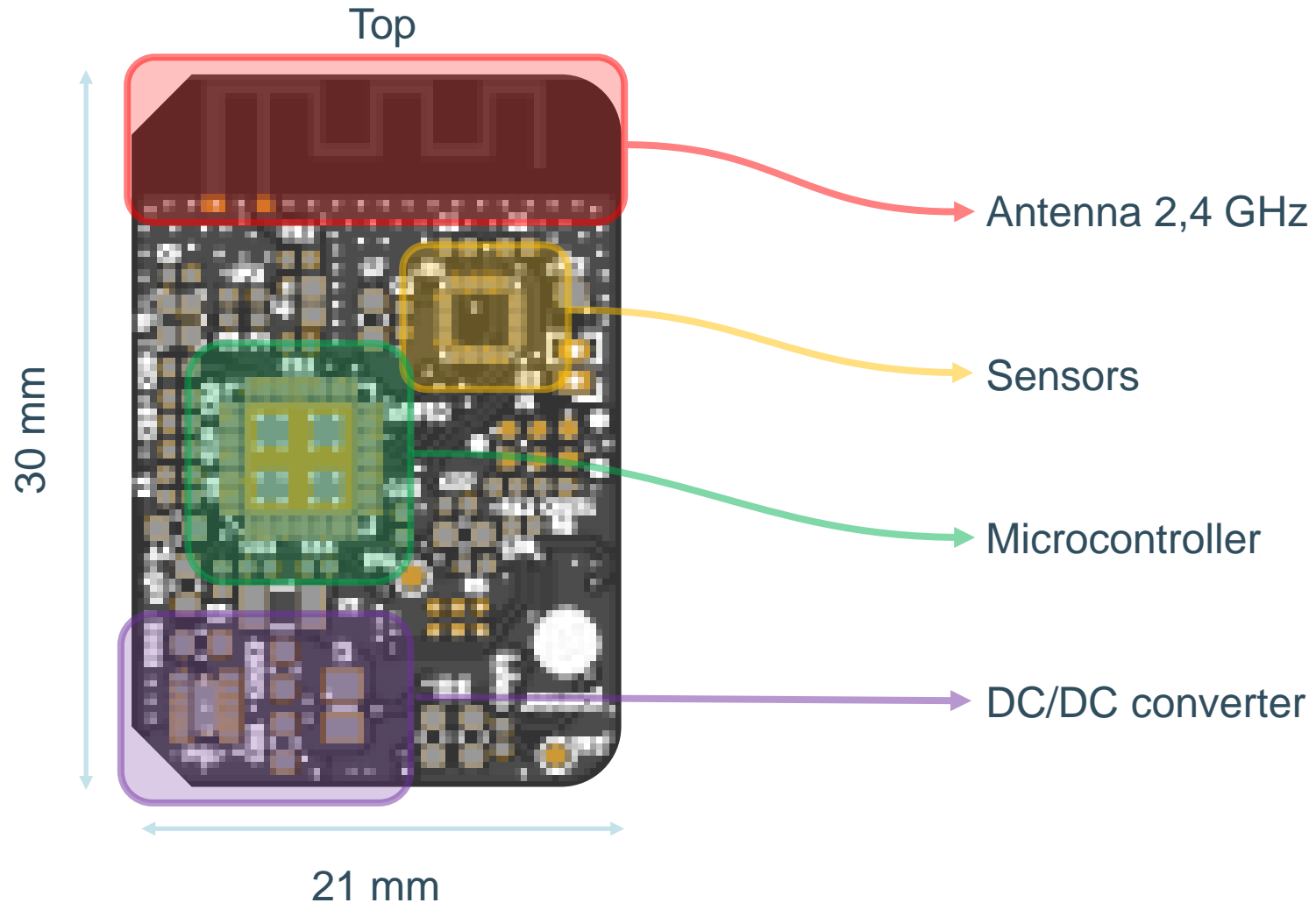
(Store calibration params in flash memory)



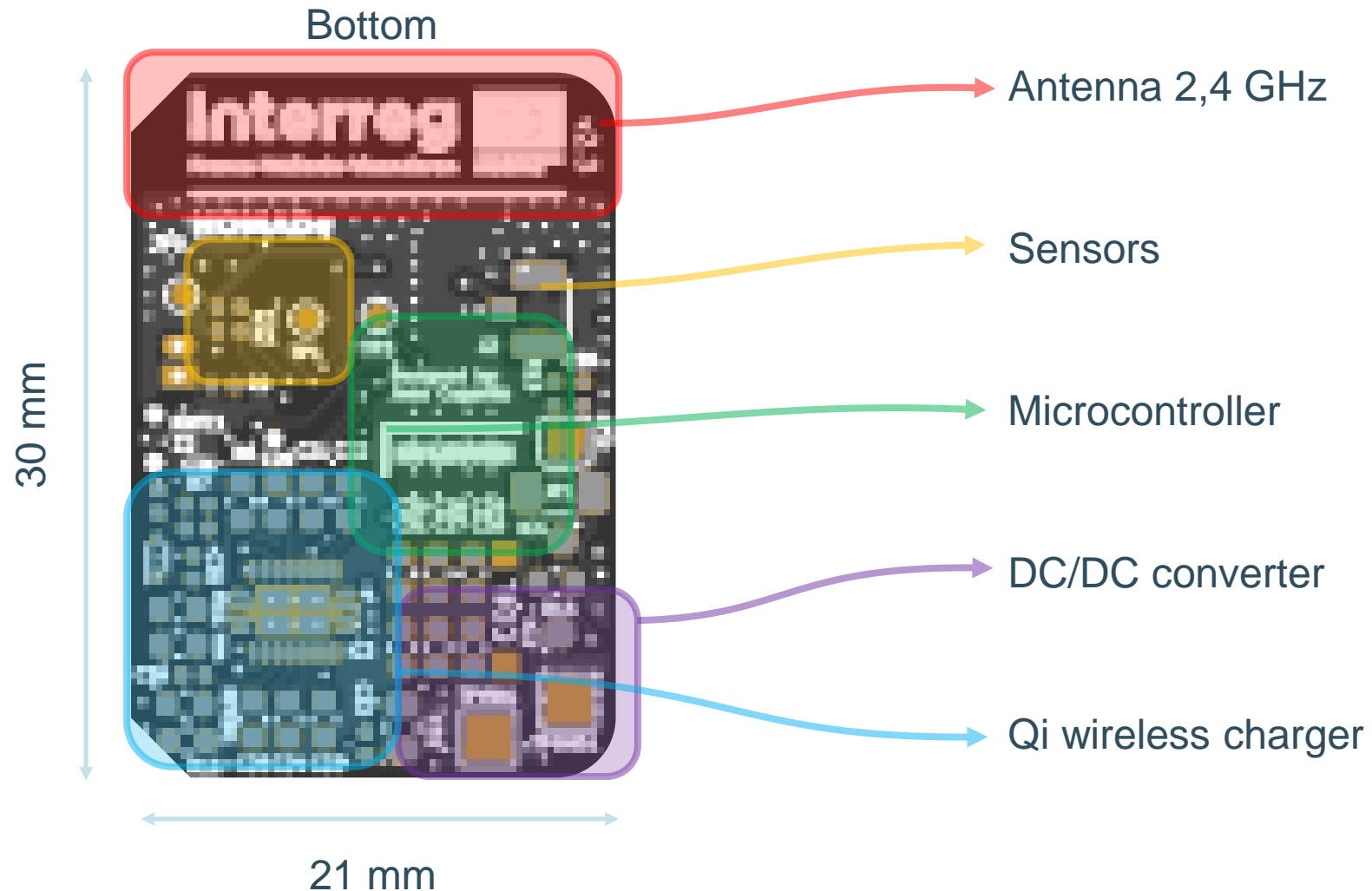
Remote update

(Via smartphone over BLE)

# SYSTEM | CIRCUIT ANALYSIS



# SYSTEM | CIRCUIT ANALYSIS



# BLOCK DIAGRAM

ICM-20948 TDK Invensense

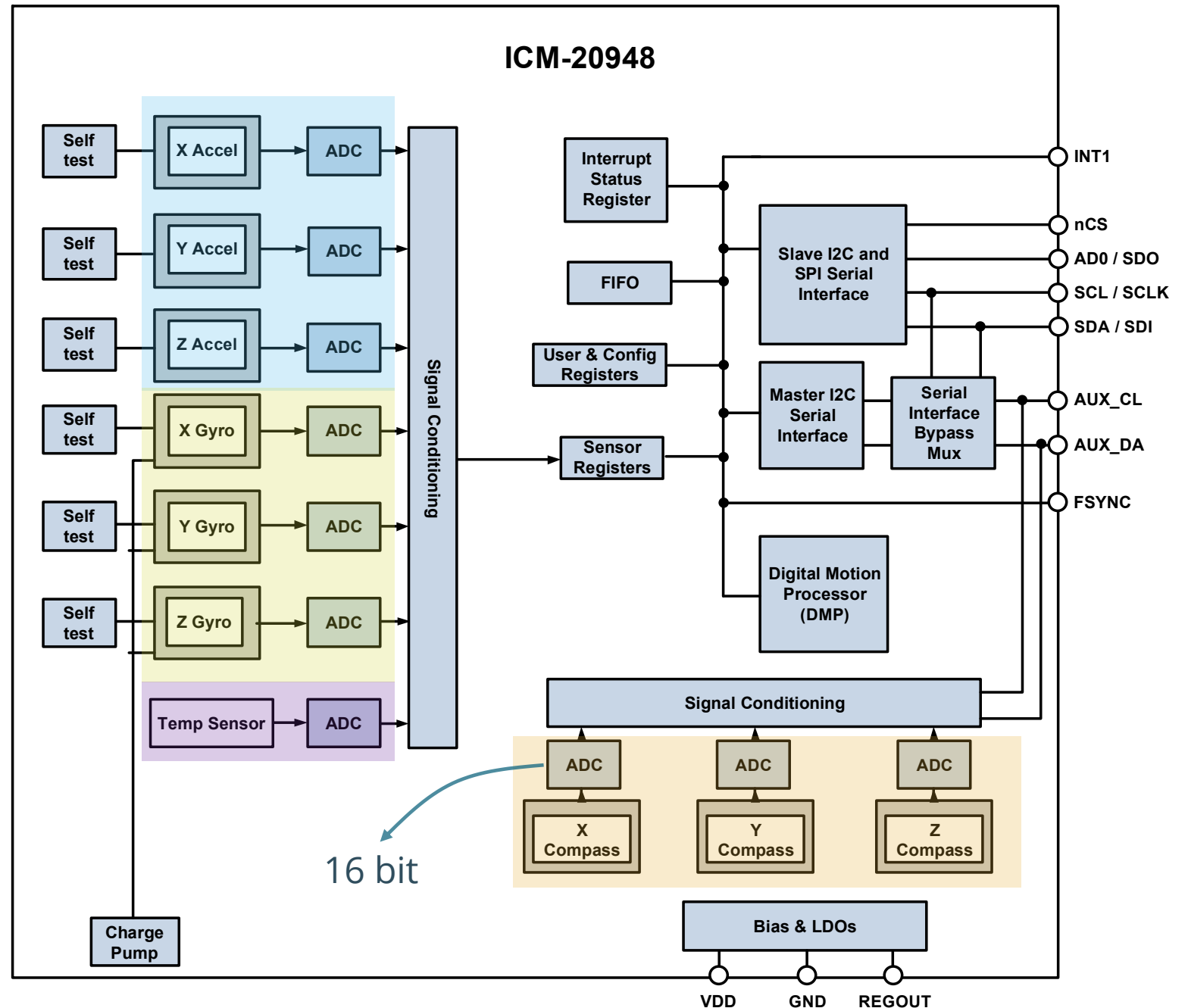
## Sensors

*Accelerometer [m/s<sup>2</sup>]*

*Gyroscope [dps]*

*Temperature [°C - F]*

*Compass [μT]*



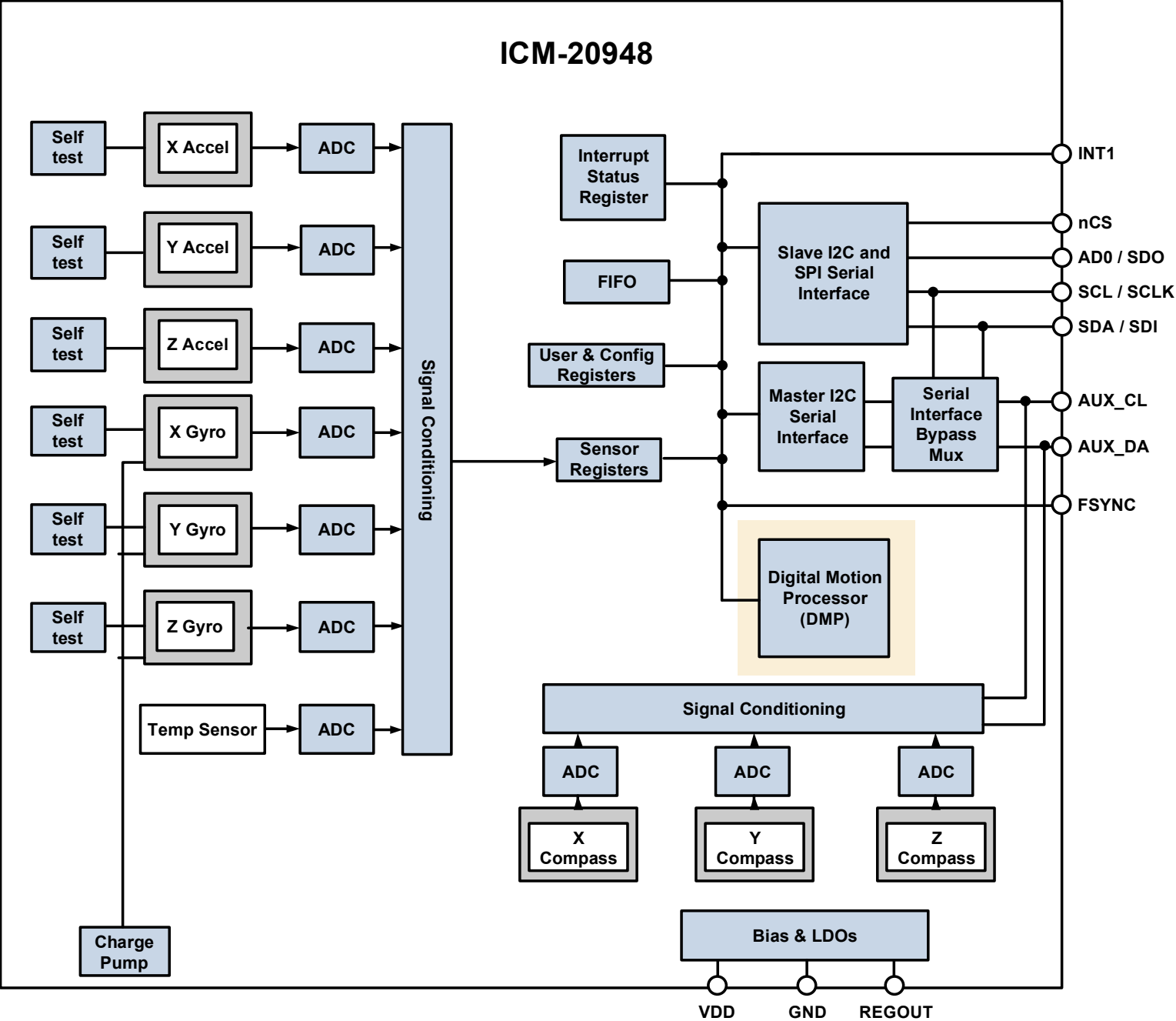
# BLOCK DIAGRAM

ICM-20948 TDK Invensense

Sensor Fusion

Digital Motion Processor  
(DMP)

RAW data → Orientation  
(3 sensor types)

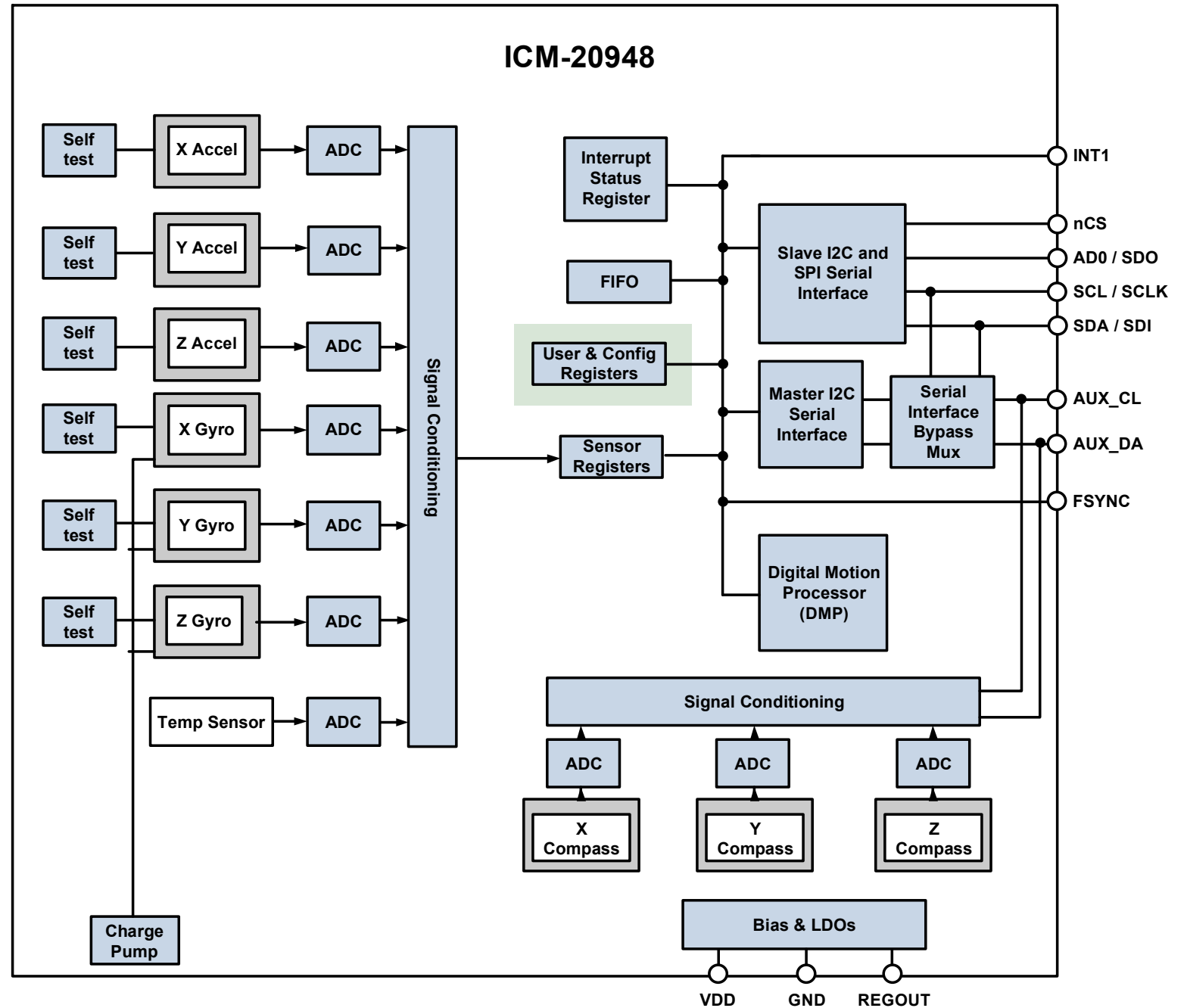


# BLOCK DIAGRAM

ICM-20948 TDK Invensense

Configuration registers

Calibration



# SYSTEM | TYPICAL SETTINGS

Full Scale Range (**FSR**) ( $\equiv$  sensor sensitivity)

Gyroscope  $\pm 250\text{ dps}$ ,  $\pm 500\text{ dps}$ ,  $\pm 1000\text{ dps}$ , ,  $\pm 2000\text{ dps}$

Accelerometer  $\pm 2g$ ,  $\pm 4g$ ,  $\pm 8g$ ,  $\pm 16g$

Compass  $\pm 4900\text{ }\mu T$

Output Data Rate (**ODR**)

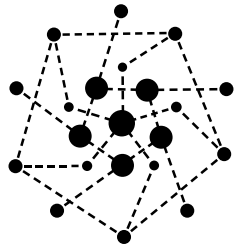
Gyroscope  $\pm 4\text{ Hz}$  –  $0,5\text{ kHz}$

Accelerometer  $< 1\text{ Hz}$  –  $0,5\text{ kHz}$

Compass  $10\text{ Hz}$  -  $100\text{ Hz}$

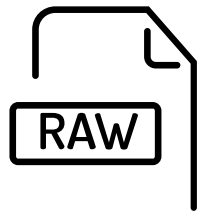
DMP enable/disable

# SYSTEM | DATA OUTPUT NOMADE SENSOR



Quaternions / Euler angles - 6 DoF

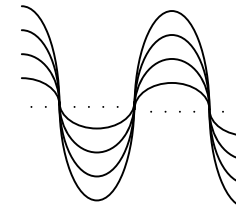
Quaternions / Euler angles - 9 DoF



Gyroscope (dps)

Accelerometer (mg)

Magnetometer ( $\mu$ T)



50 Hz

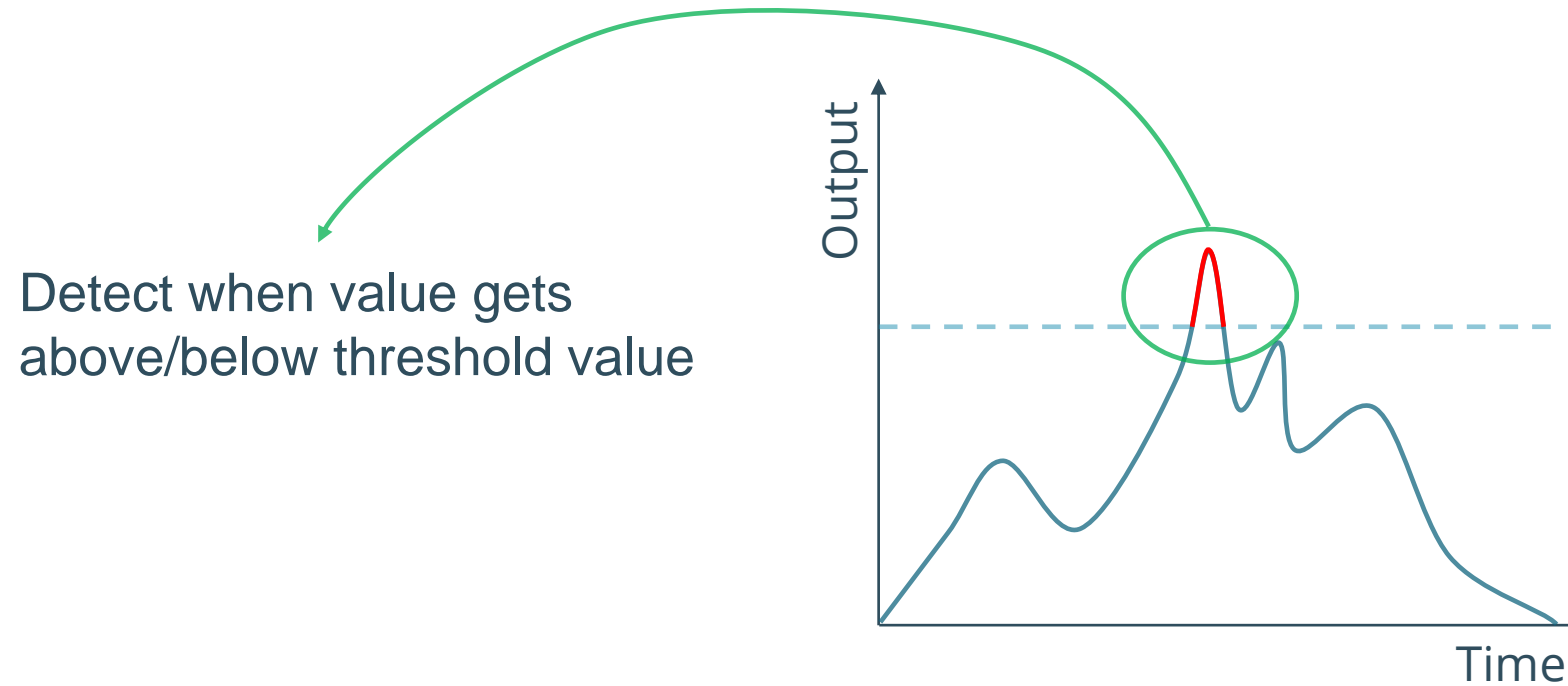
100 Hz

# SYSTEM | POST PROCESSING

Examples:

- Threshold detection algorithm
- Recognising patterns with machine learning
- Detecting entropy

- Threshold detection algorithm



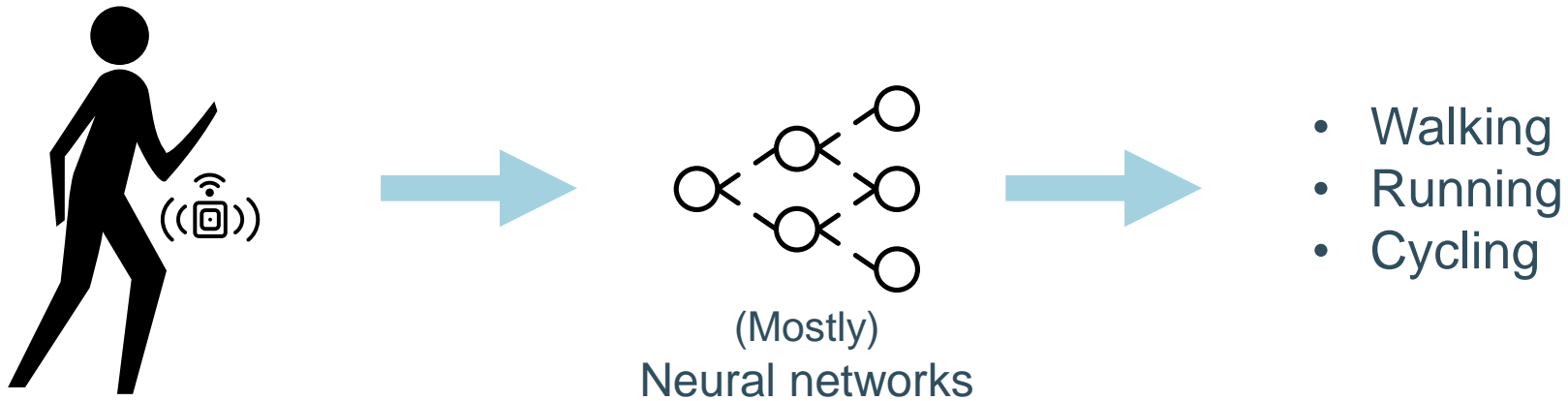
- Recognising patterns with machine learning

# SYSTEM | POST PROCESSING

Examples:

- Threshold detection algorithm
- Recognising patterns with machine learning
- Detecting entropy

- Threshold detection algorithm
- Recognising patterns with machine learning



- Detecting entropy

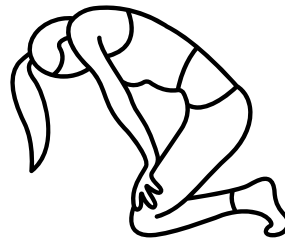
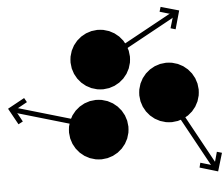
# SYSTEM | POST PROCESSING

Examples:

- Threshold detection algorithm
- Recognising patterns with machine learning
- Detecting entropy

- Threshold detection algorithm
- Recognising patterns with machine learning
- Detecting entropy

Variance in movements → Consistency of exercises  
→ Low back pain



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**CHALLENGES**  
CONCLUSION

# CHALLENGES | WHICH?

- Movement tracking with IMU
- Calibration
- Synchronization
- Power consumption

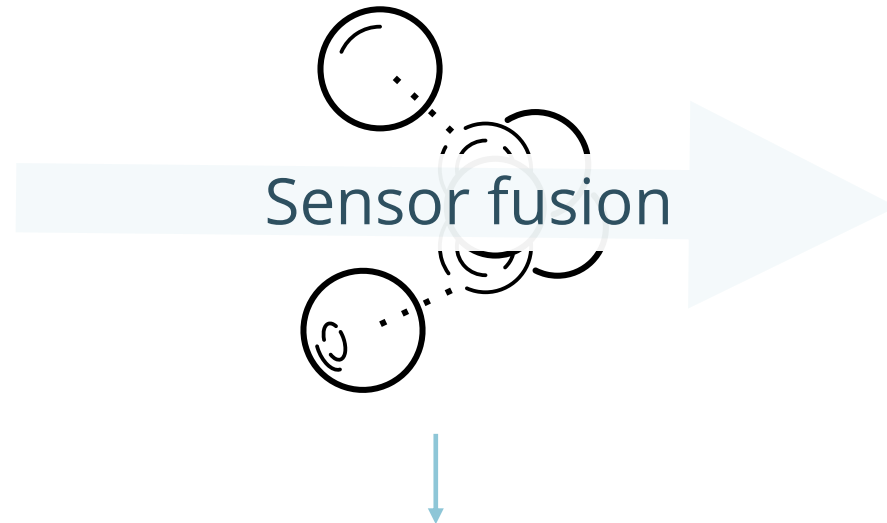
# CHALLENGES | WHICH?

- **Movement tracking with IMU**
- Calibration
- Synchronization
- Power consumption

# CHALLENGES | MOVEMENT TRACKING WITH IMU

Obtain **RAW data**

- Accelerometer
- Gyroscope
- (Magnetometer)



Kalman filter  
Complementary filter  
Madgwick filter

6 DoF / 9 DoF

**Orientation** & rotation info

- Quaternions
- Euler Angles
- Tait-Bryan angles

# CHALLENGES | MOVEMENT TRACKING WITH IMU

6 DoF / 9 DoF

## **Orientation** & rotation info

- Quaternions
- Euler Angles
- Tait-Bryan angles

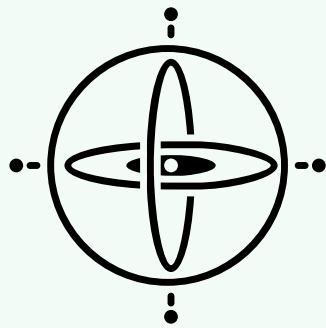
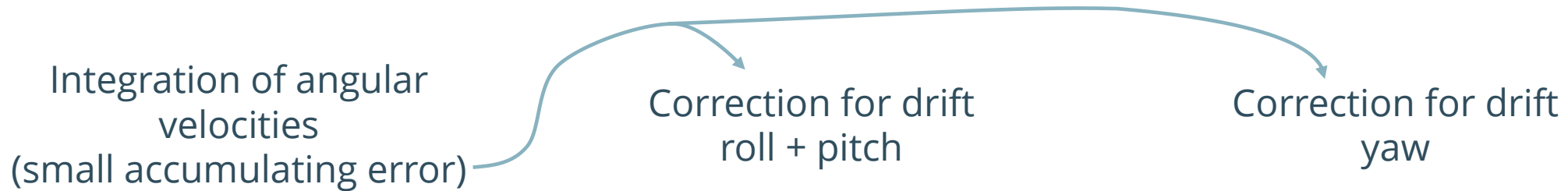
*Rotation*

Relative values

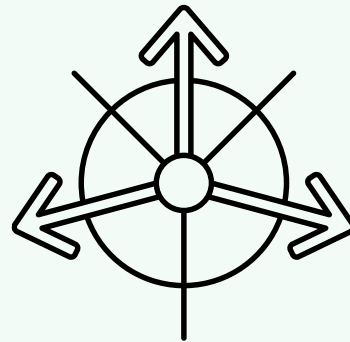
*Orientation*

How an object is placed in space  
Refer to a reference placement

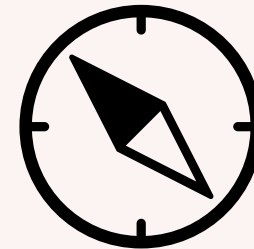
# CHALLENGES | MOVEMENT TRACKING WITH IMU



Gyroscope



Accelerometer



Magnetometer

6 Degrees of Freedom (DoF)

9 DoF

# CHALLENGES | WHICH?

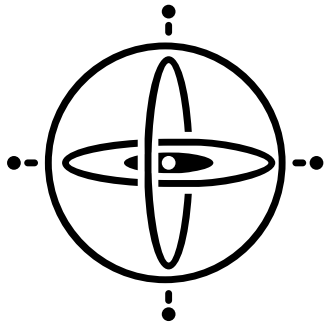
- Movement tracking with IMU
- **Calibration**
- Synchronization
- Power consumption

# CHALLENGES | CALIBRATION

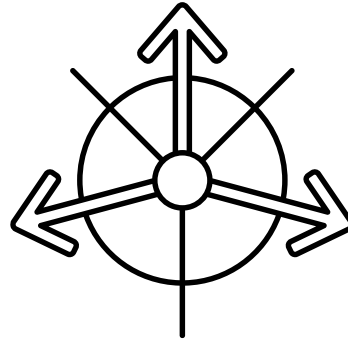


To ensure the sensor performs according to the specification  
and to provide meaning to the electrical output

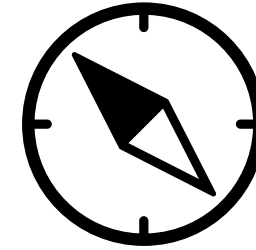
# CHALLENGES | CALIBRATION ERRORS



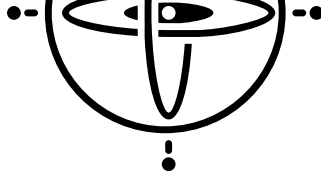
Offset + Scale



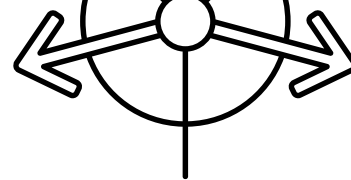
Offset + Scale



Hard + Soft iron distortions



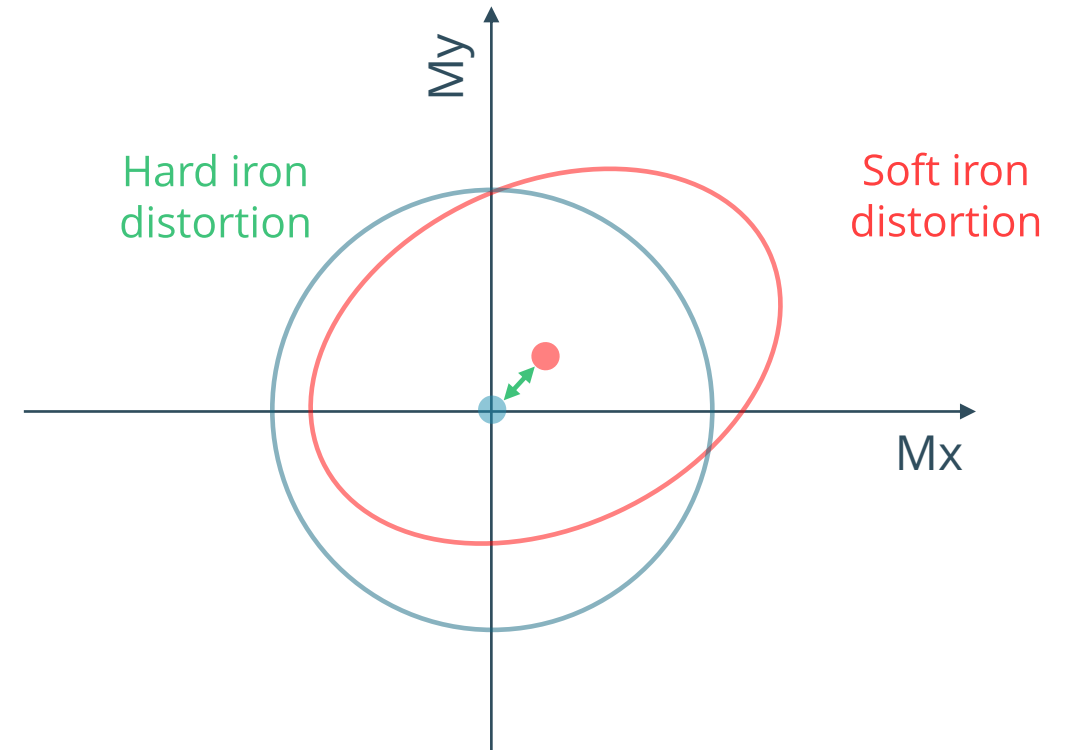
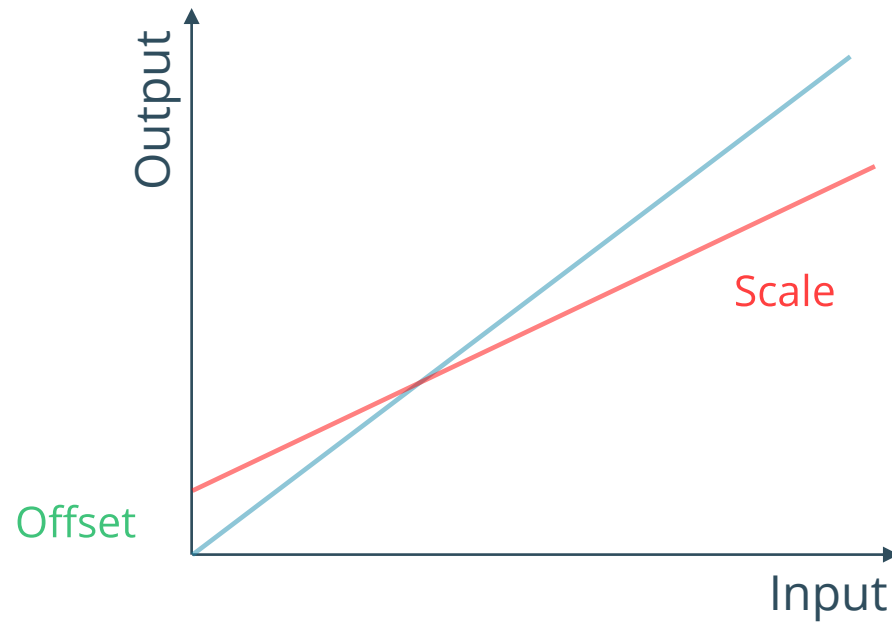
Offset + Scale



Offset + Scale



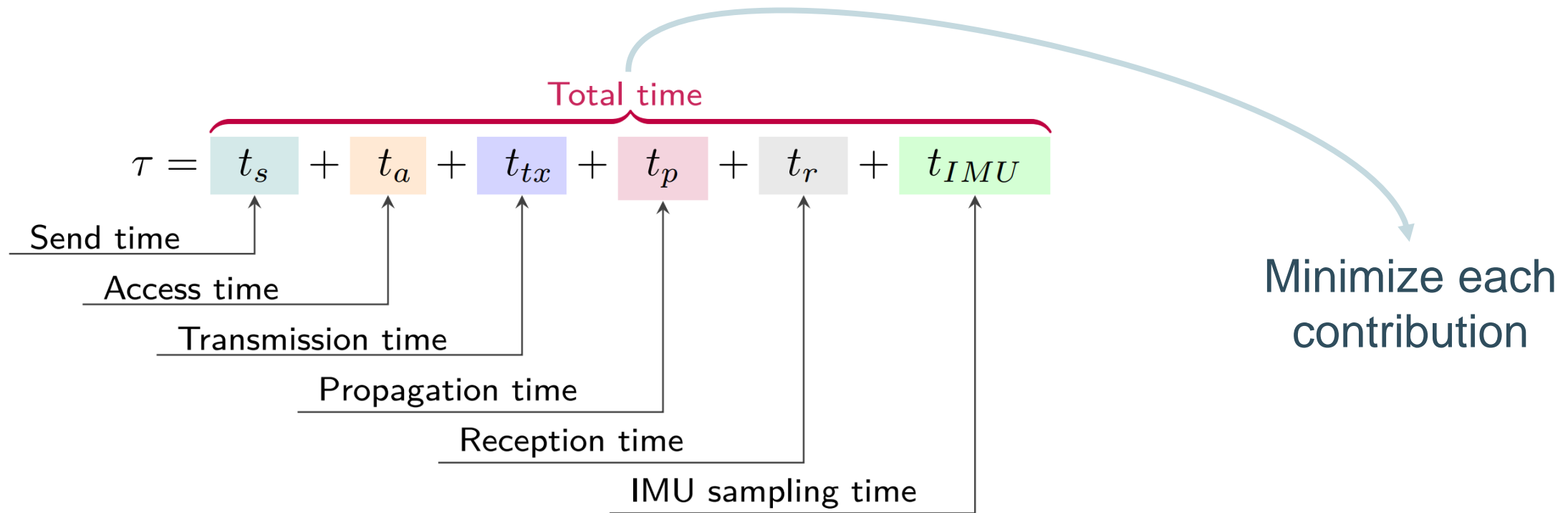
Hard + Soft iron distortions



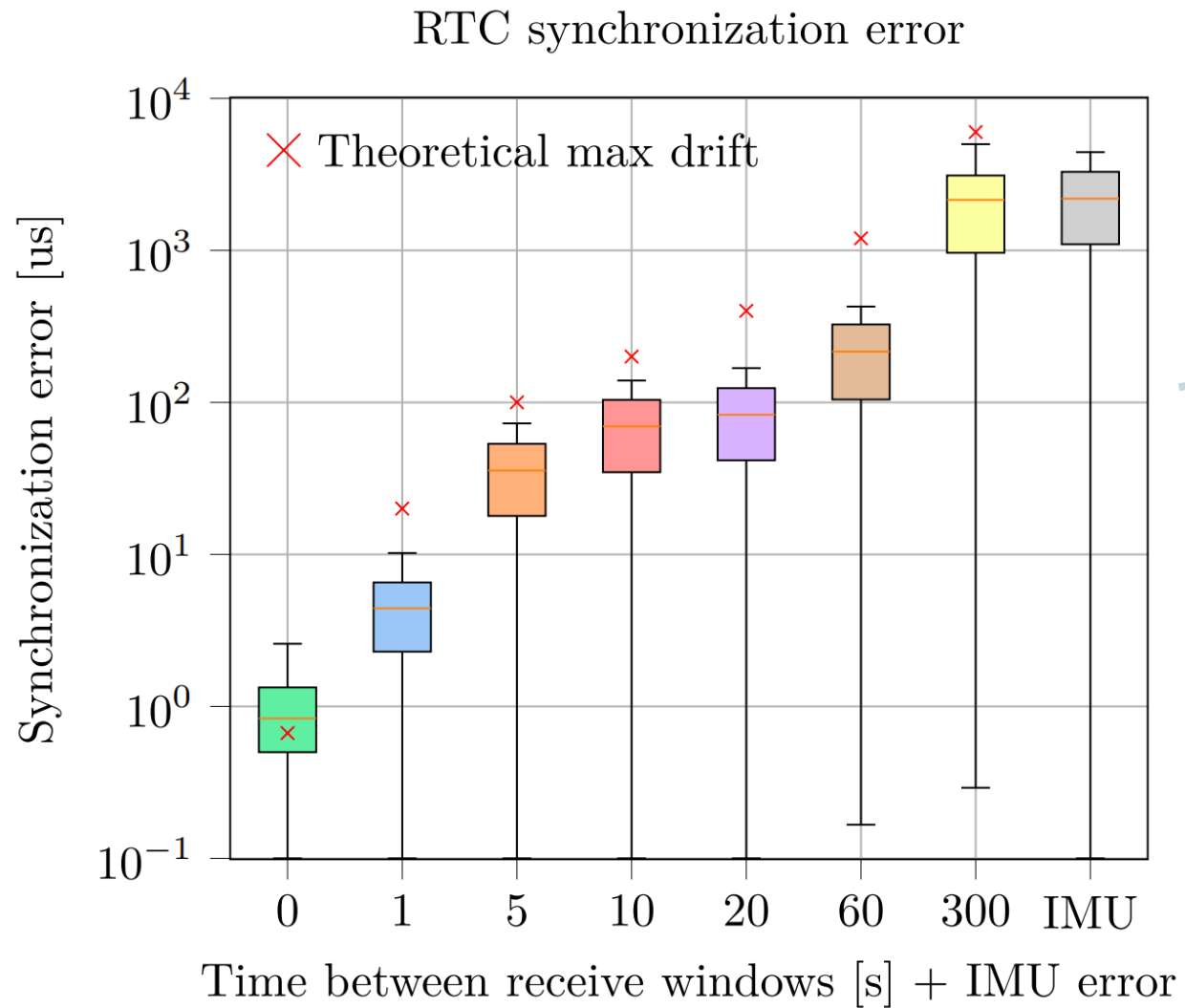
# CHALLENGES | WHICH?

- Movement tracking with IMU
- Calibration
- **Synchronization**
- Power consumption

# CHALLENGES | SYNCHRONIZATION



# CHALLENGES | SYNCHRONIZATION



Microsecond level wireless  
synchronization accuracy  
over BLE link

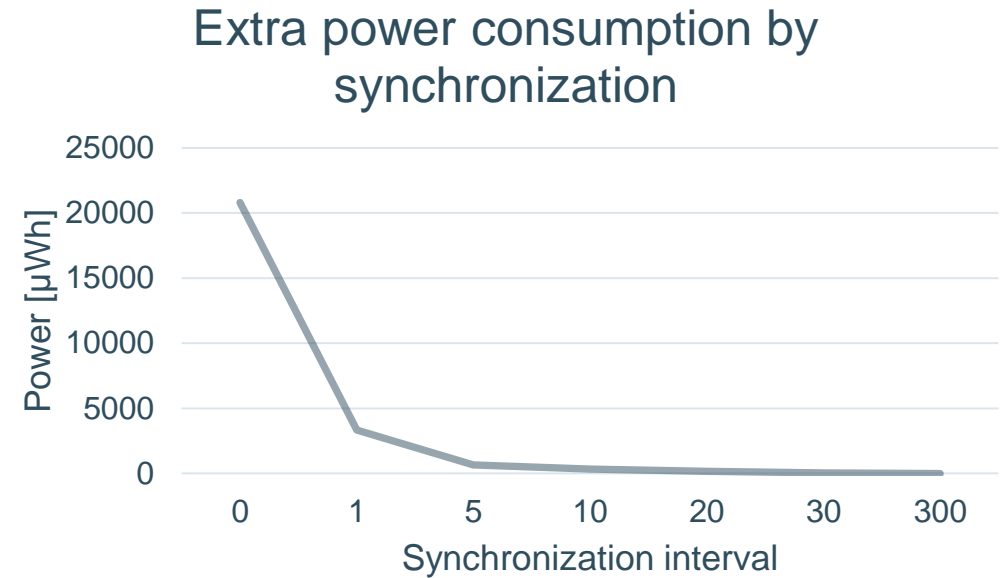
# CHALLENGES | WHICH?

- Movement tracking with IMU
- Calibration
- Synchronization
- **Power consumption**

# CHALLENGES | POWER CONSUMPTION

## Low Power Components & Design

IMU Supply Currents		
9-Axis (DMP disabled)	3.11	mA



50+ hours battery life

INTRODUCTION  
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CHALLENGES  
CONCLUSION

# SENSOR SYSTEM | CONCLUSIONS



- ✓ Flexible
- ✓ User friendly
- ✓ Affordable
- ✓ Synchronised
- ✓ Publications

## OUR PUBLICATIONS (Linked to NOMADe project)

Cappelle, J., Monteyne, L., Van Mulders, J., Goossens, S., Vergauwen, M., Van der Perre, L. with Cappelle, J. (corresp. author) (2020). **Low-Complexity Design and Validation of Wireless Motion Sensor Node to Support Physiotherapy.**

Sensors, 20 (21), Art.No. 6362.

doi: 10.3390/s20216362

Open Access

Van Mulders, J., Monteyne, L., Goossens, S., De Strycker, L., Van der Perre, L. with Van Mulders, J. (corresp. author) (2021). **Contactless Multi-Sensor Solution for e-Treatment of Musculoskeletal Disorders.**

IEEE Access.

doi: 10.1109/ACCESS.2021.3055067

Open Access

## PUBLICATIONS WITH OUR SENSOR SYSTEM

Blandeau, Mathias, et al. "IMU positioning affects range of motion **measurement during squat motion analysis.**"

Journal of Biomechanics 153 (2023): 111598.

Guichard, Romain, Mathias Blandeau, and Sebastien Leteneur. "Localization of **IMU sensors affects the estimation of soft tissue wobbling: A preliminary study.**"

Comput. Methods Biomech. Biomed.  
Eng 24.3 (2021).

Blandeau, M.; Guichard, R.; Hubaut, R.; Leteneur, S. **Two-Step Validation of a New Wireless Inertial Sensor System: Application in the Squat Motion.**

Technologies 2022, 10, 72.

<https://doi.org/10.3390/technologies10030072>

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Guichard, Romain, Mathias Blandeau, and Sebastien Leteneur. "Localization of IMU sensors affects the estimation of soft tissue wobbling: A preliminary study."

Comput. Methods Biomech. Biomed.  
Eng 24.3 (2021).

Study on

- IMU placement
- Artefact measurements induced by soft tissue wobbling



# Interreg

France-Wallonie-Vlaanderen



UNION EUROPÉENNE  
EUROPESE UNIE

## NOMADe



AVEC LE SOUTIEN DU FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL  
MET STEUN VAN HET EUROPEES FONDS VOOR REGIONALE ONTWIKKELING

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Antwerpen

FORS

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Université de Mons

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Picardie  
Jules Verne

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national  
recherche  
handicap

MareTak

BBS

FFMKR

+

CHwapi

CHwapi

Ma'hera

Fibromyalgie  
France

tivoli

Vivatia

SPPC

GHdC

GHdC

GHdC

KENAZENTER

## Een multidisciplinaire benadering van neuro-musculo-skeletale aandoeningen ten dienste van de therapeut

De oorsprong van neuromusculoskeletale aandoeningen (NMSA) is multifactorieel. De professionele risicofactoren zijn geïdentificeerd. Ze zijn biomechanisch van aard, maar ook psychosociaal. Om het effect van NMSA te beperken en de aanpak doeltreffend te maken, moet worden ingegrepen in de organisatie van de zorg.

Met het oog hierop en in het kader van het NOMADE-project zijn verschillende acties uitgevoerd om kennis, opleidingsmodules of digitale instrumenten te verspreiden:

Alle hulpmiddelen zijn online te raadplegen

## Klinische test & Künstliche Intelligenz (AI)



Veranderingen in motorische patronen worden verwacht bij patiënten met neuro-musculo-skeletale aandoeningen in vergelijking met gezonde personen. Dergelijke dynamische veranderingen kunnen worden beoordeeld door het analyseren van tijdreeksen die van de beweging van een patiënt zijn opgenomen.

In het geval van lage rugpijn en nekpijn kunnen AI of niet-lineaire analysetechnieken patiënten doeltreffend identificeren.

## Bewegungssensoren & NOMADe-applicatie

Een contactloze multi-senseroplossing voor de beoordeling van menselijke bewegingen is ontwikkeld en gevalideerd in verschillende praktijksituaties. De gekozen oplossing is van het type "lage complexiteit": lage kosten, gemakkelijk te gebruiken door klinici in professionele situaties.

Deze sensoren zijn gekoppeld aan een toepassing die de opslag van heterogene gegevens, sensoren en klinische tests mogelijk maakt.



## Het familiespel hypothese



Een nieuw pedagogisch instrument om te leren klinisch te redeneren in de vorm van een leuk, eenvoudig en gestructureerd kaartspel dat kan worden gebruikt door docenten in kinesitherapie-opleidingen en hun studenten.

## Didren R



Een virtuele versie van de zogenaamde "DidRen" klinische test om de cervicale mobiliteit te beoordelen met behulp van een richtstelsel met laserstraal, waarbij de laserstraal wordt bewogen door rotaties van de nek (Hage & Aernsma, 2009; Hage et al., 2020).

## E-learning interventie rond aanpak van lage rugklachten

Een interactieve e-learning module om bio-psycho-sociaal beheer van lage rugpijn bij gezondheidswerkers te promoten: een pilootstudie bestaande uit 3 videomodules

- Evaluatie en diagnostisch triage van een patiënt met lage rugdachten
- Aanpak van een patiënt met lage rugdachten
- Inzicht in de complexiteit van pijn



# Contactless Multi-sensor Solution to Support Physiotherapy

08/06/2023

BIOSINT Meeting

Jona Cappelle



**NOMADe**



AVEC LE SOUTIEN DU FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL  
MET STEUN VAN HET EUROPEES FONDS VOOR REGIONALE ONTWIKKELING