

KU LEUVEN

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Implementation Industry 4.0 Paradigm in Education. Ukrainian Experience
“Boosting the role of HEIs in the industrial transformation towards the Industry 4.0 paradigm in Georgia and Ukraine” 609939-EPP-1-2019-1-BE-EPPKA2-CBHE-JP-HEIn4

Contactless Multi-sensor Solution to Support Physiotherapy

Jona Cappelle



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

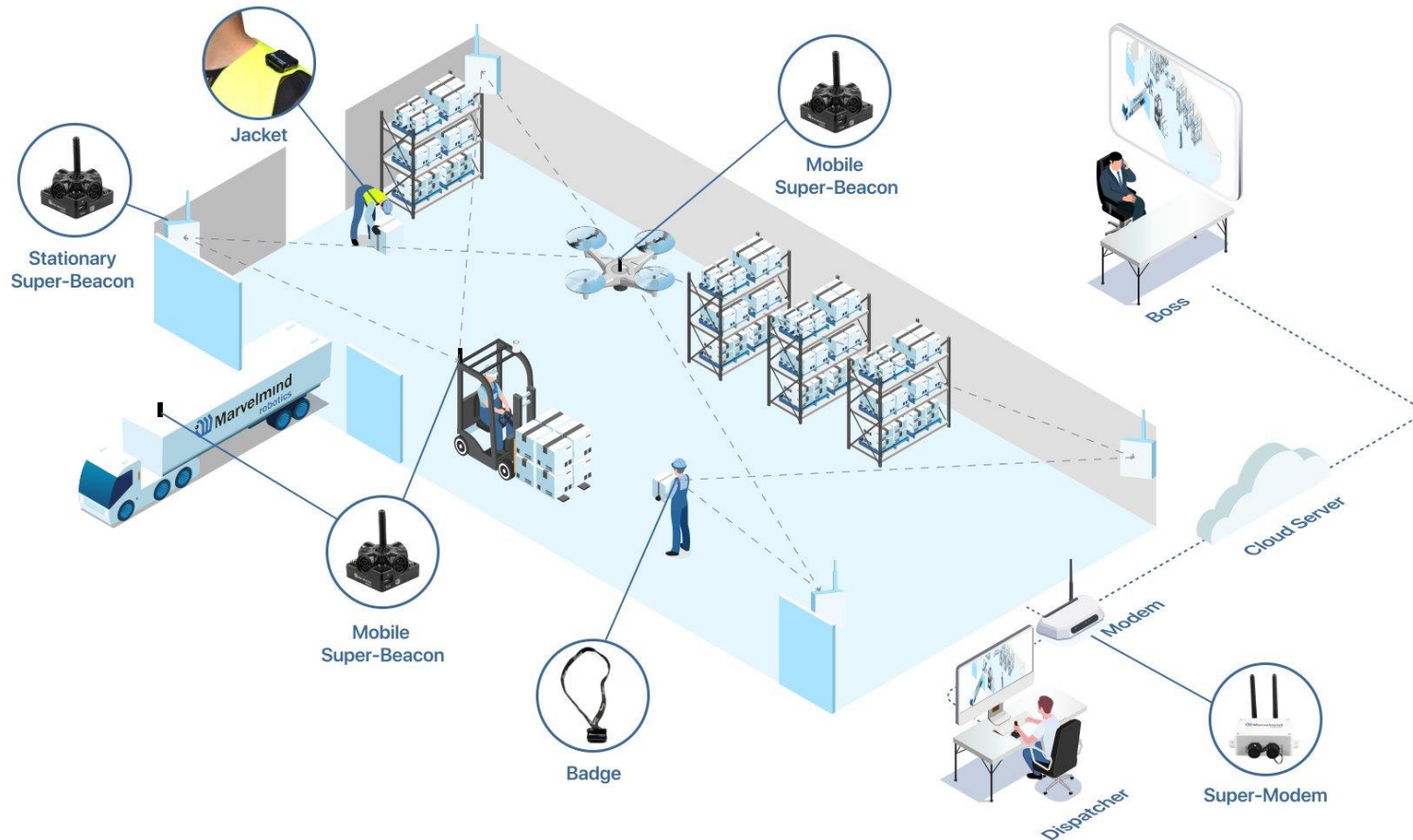
Ultra-wideband positioning solution with accuracy of 10 cm



SOLUTIONS | MOTION TRACKING SYSTEMS

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

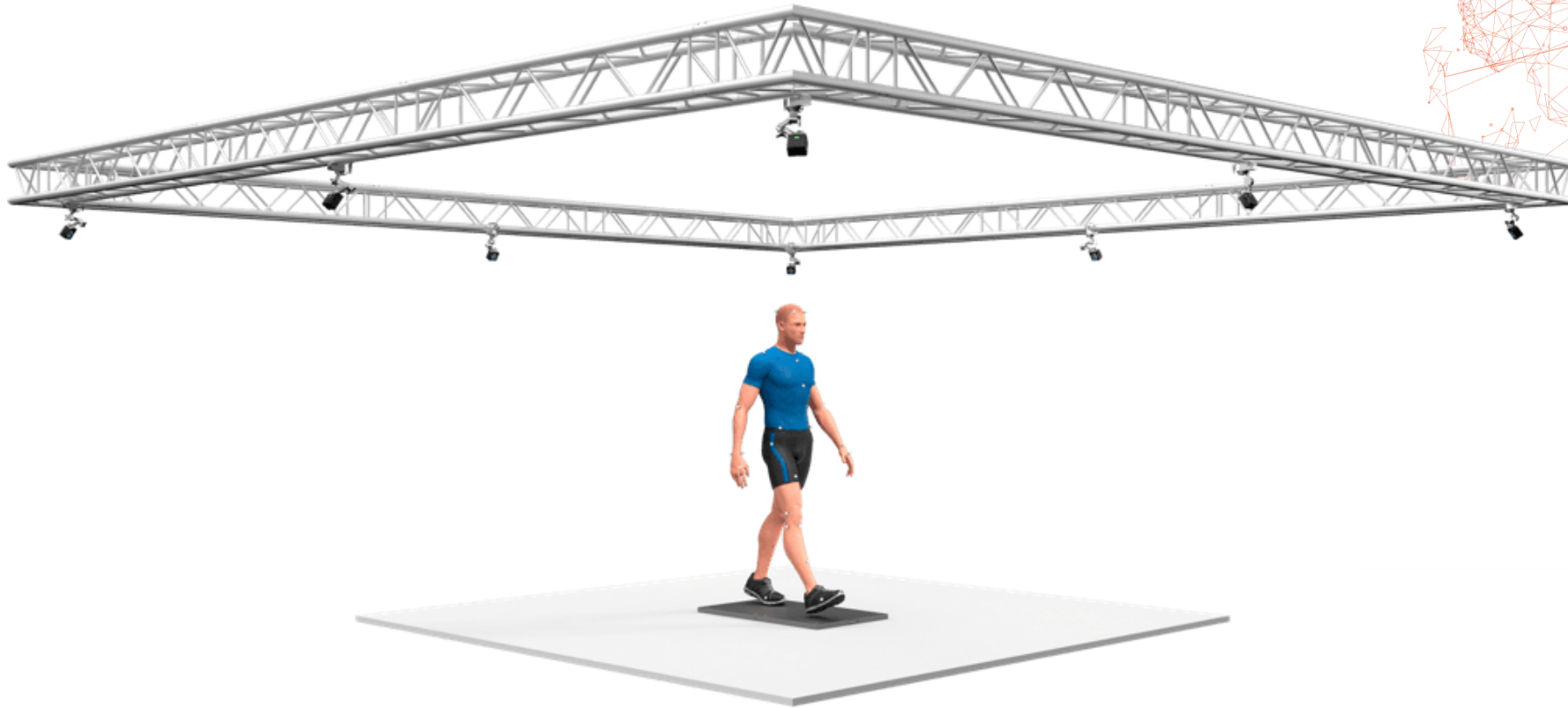
for autonomous robots, drones, vehicles and humans



SOLUTIONS | MOTION TRACKING SYSTEMS

Accurate camera-based systems

Error of 0.2 mm or less



SOLUTIONS | ON-BODY SENSORS

Real-time full body motion capture system

IMU-based sensing system



INTRODUCTION
POSSIBLE SOLUTIONS
RESULTING SYSTEM
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CONCLUSION

SYSTEM | OVERVIEW

Traditional visit



Practice
physiotherapist

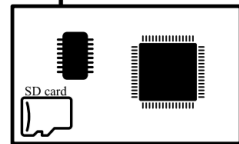
e-Treatment



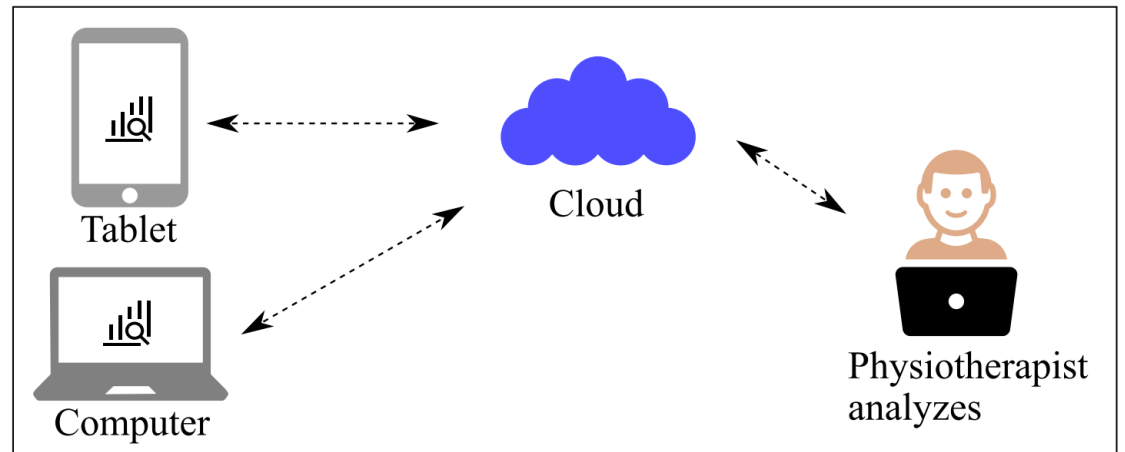
Motion sensor module



Muscle activity
sensor module



Data Capturing Unit

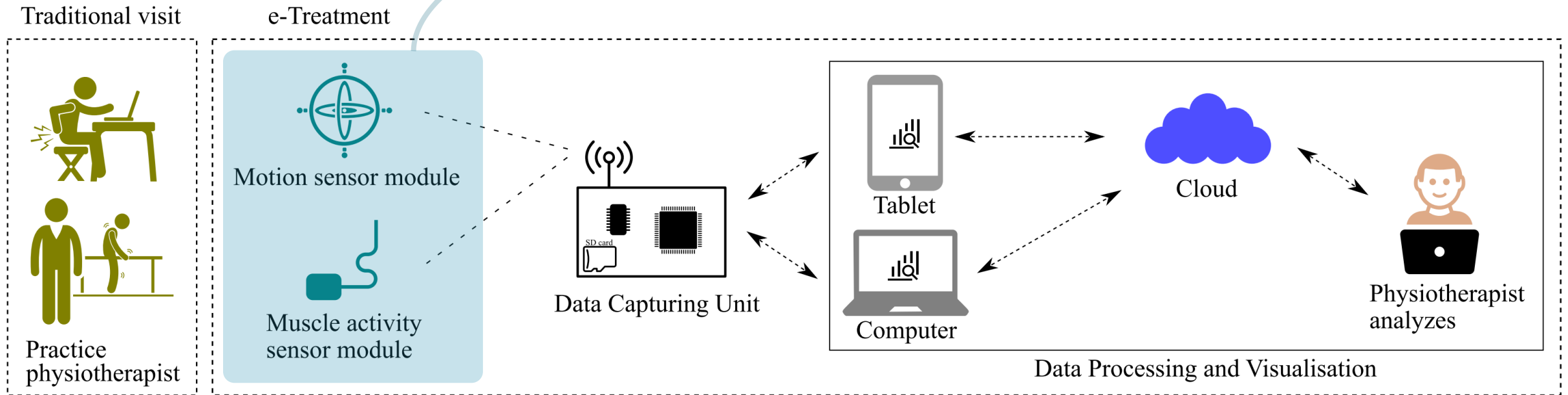


Data Processing and Visualisation

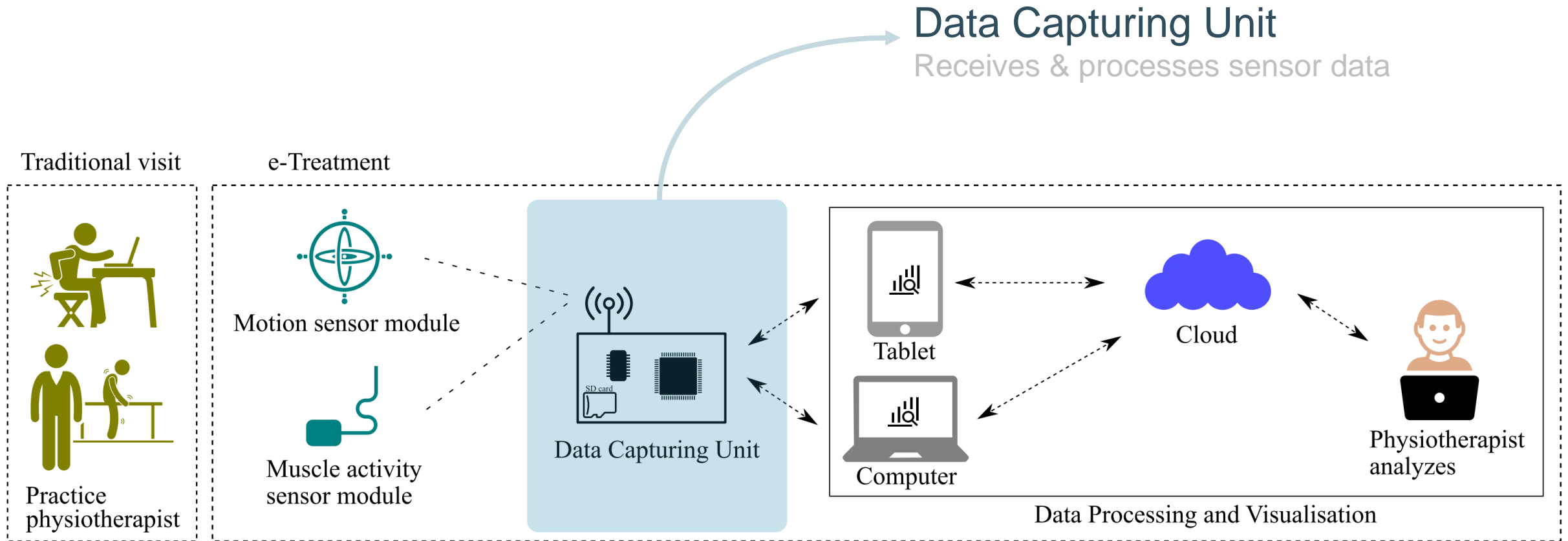
SYSTEM | OVERVIEW

IMU Sensing Modules

Measures: acceleration, angular rotation, magnetic fields



SYSTEM | OVERVIEW



Data Capturing Unit
Receives & processes sensor data

Traditional visit

e-Treatment

Motion sensor module

Muscle activity sensor module

Data Capturing Unit

Tablet

Computer

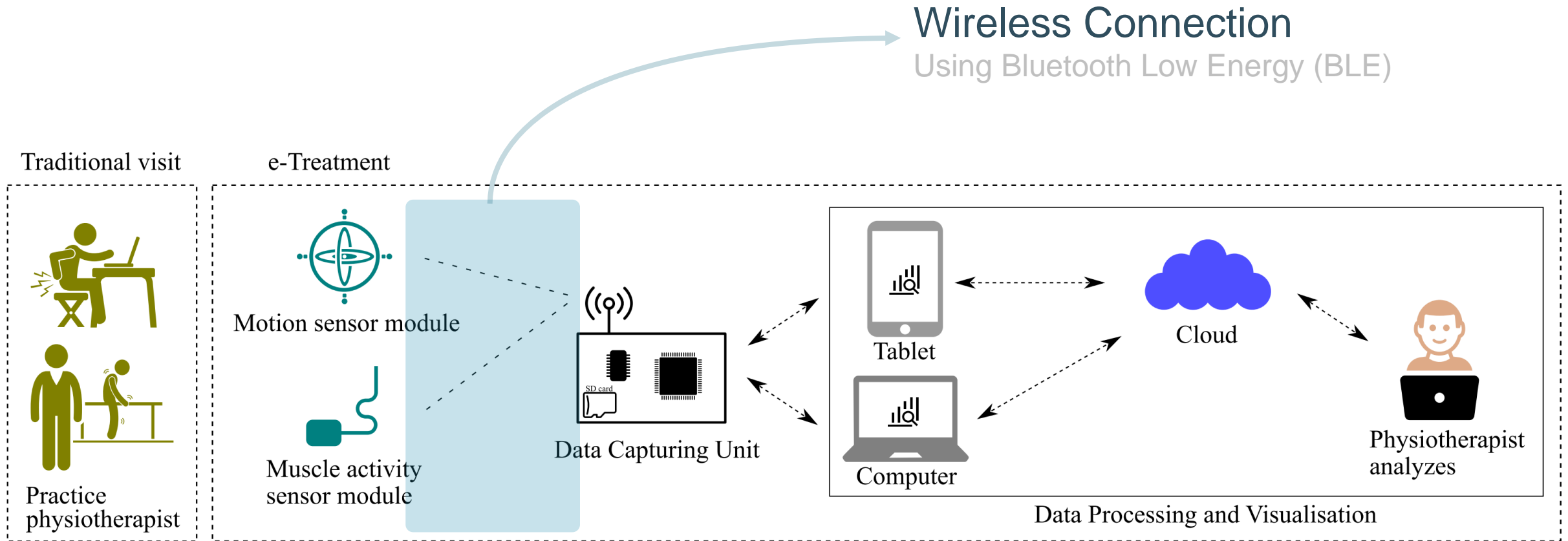
Cloud

Physiotherapist analyzes

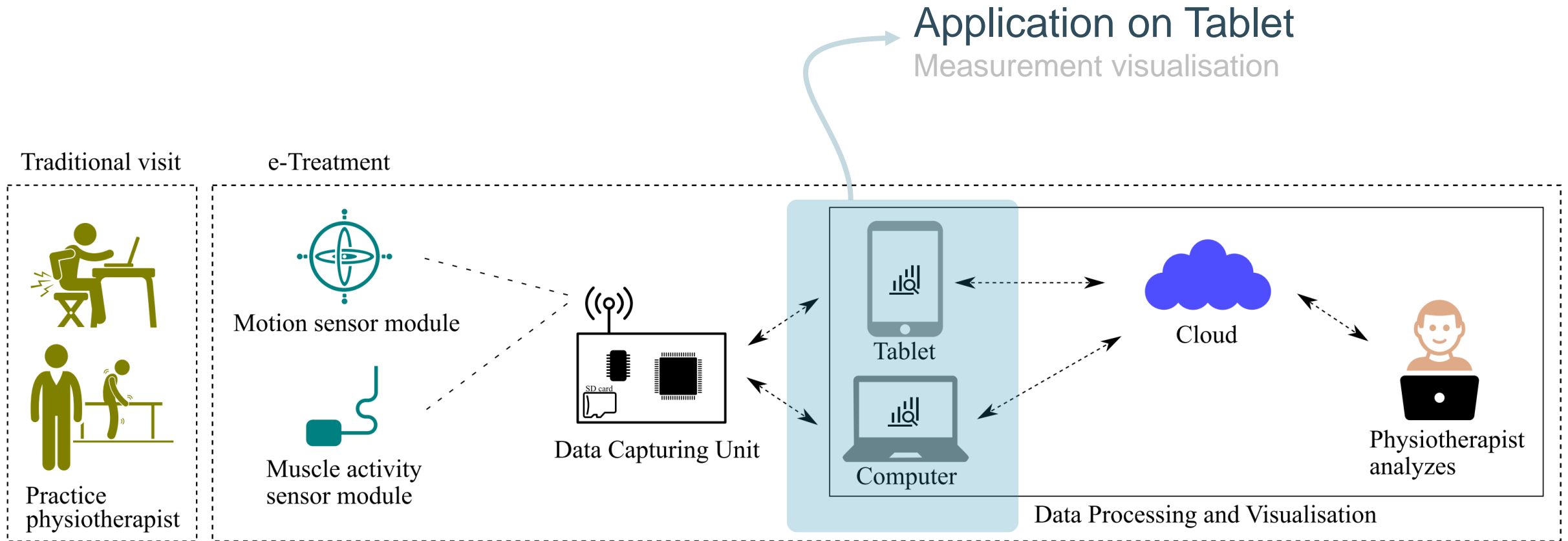
Data Processing and Visualisation

Practice physiotherapist

SYSTEM | OVERVIEW



SYSTEM | OVERVIEW

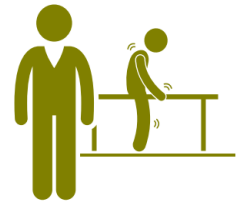


SYSTEM | OVERVIEW

Cloud Data Storage

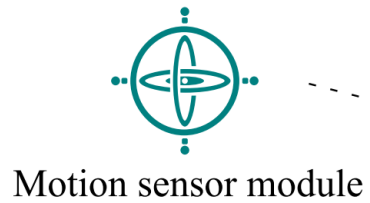
Easy to access for physiotherapist
remote treatments

Traditional visit

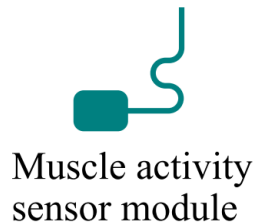


Practice
physiotherapist

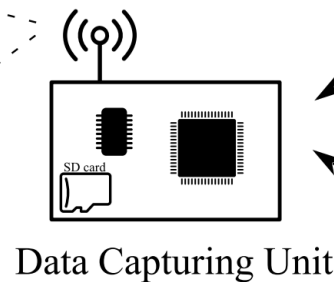
e-Treatment



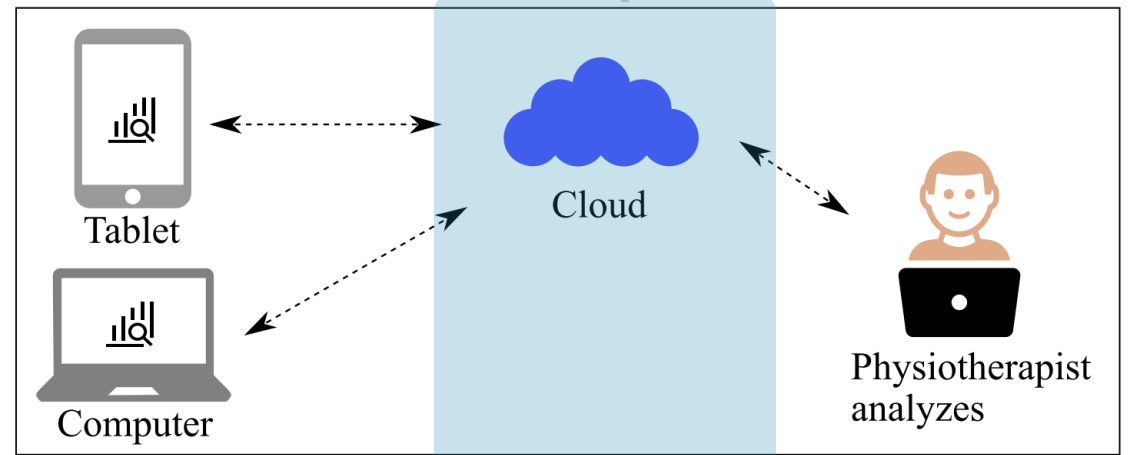
Motion sensor module



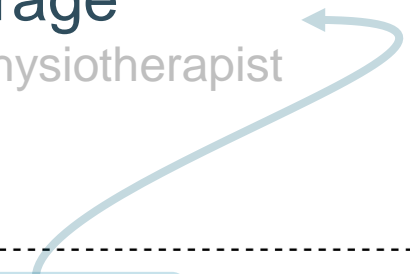
Muscle activity
sensor module



Data Capturing Unit

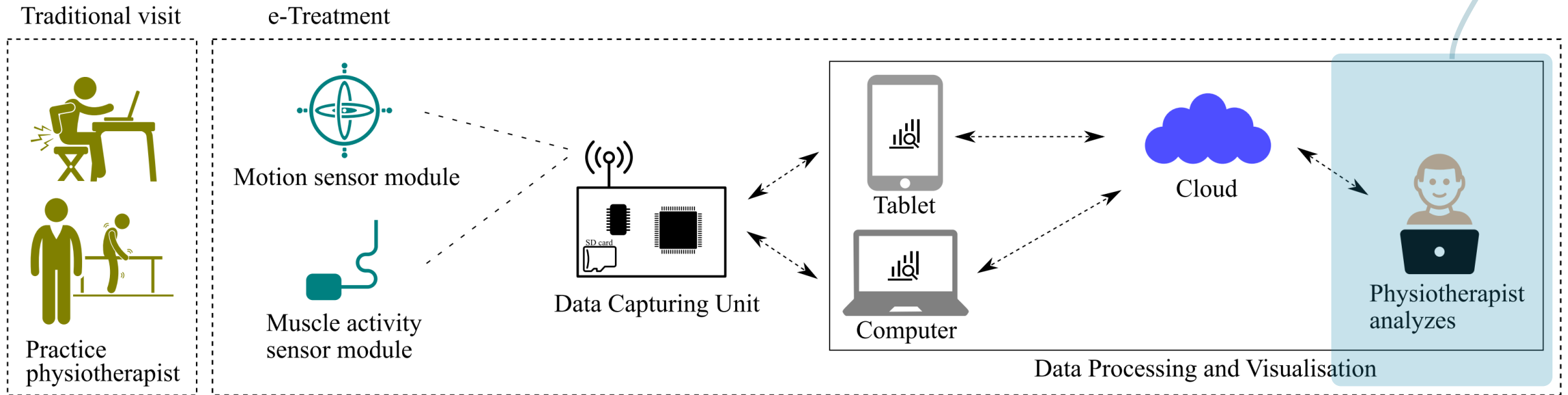


Data Processing and Visualisation



SYSTEM | OVERVIEW

(Remote) Data Analysis
By physiotherapist



SYSTEM | OVERVIEW



Motion sensors
(IMUs)



Data Capturing Unit
(DCU)

SYSTEM | OVERVIEW

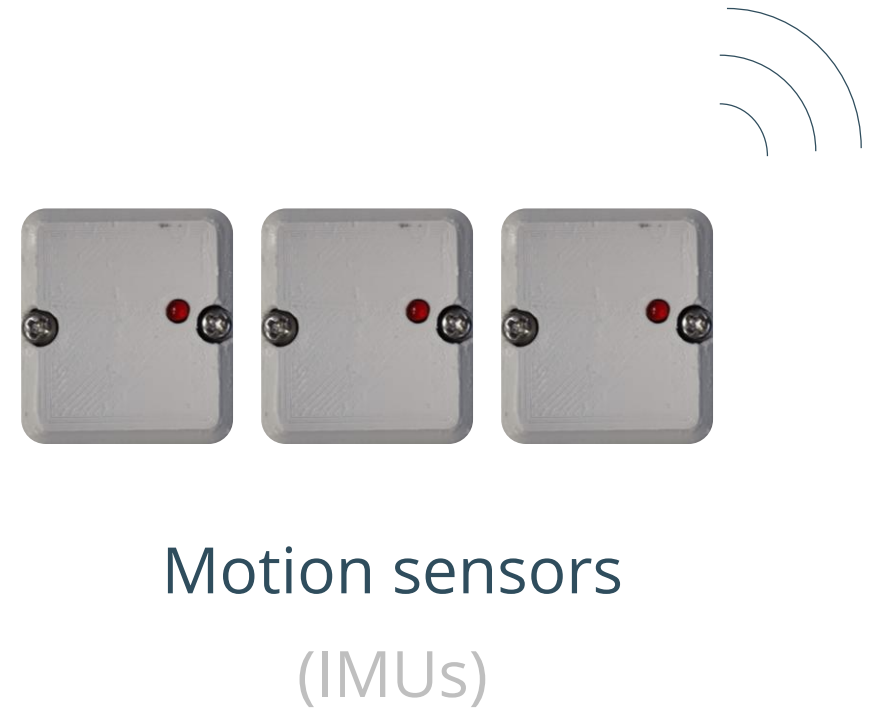
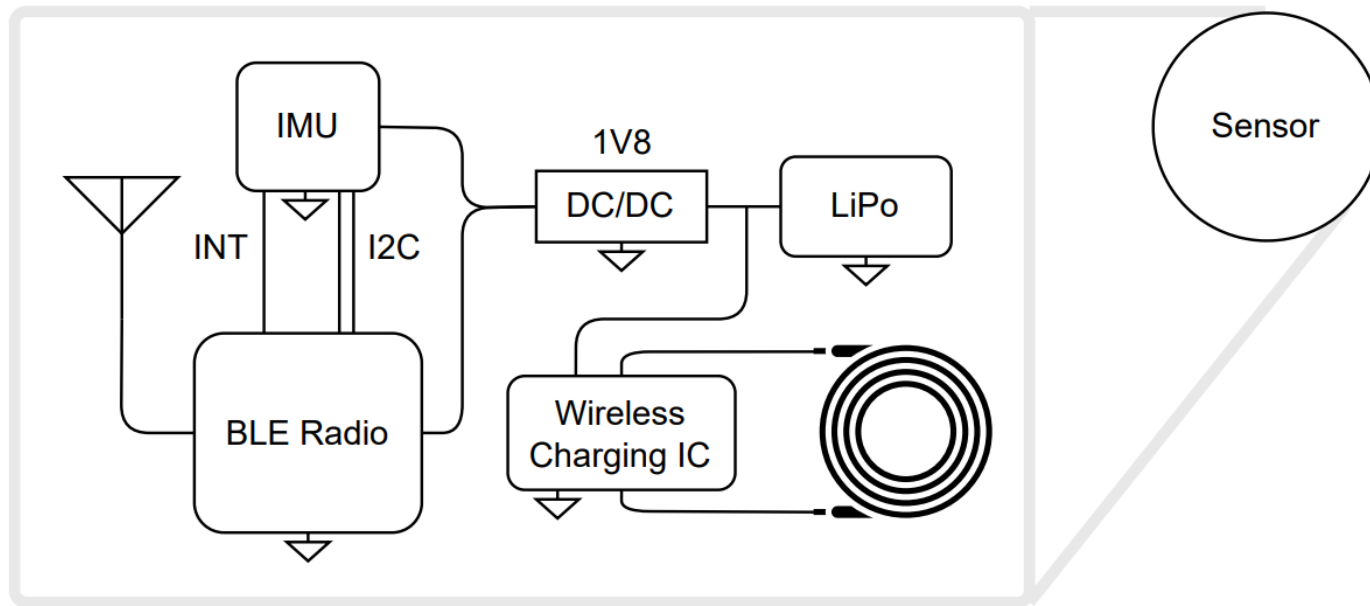


Motion sensors
(IMUs)



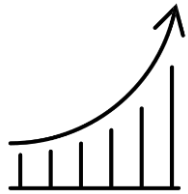
Data Capturing Unit
(DCU)

SYSTEM | SENSOR IN DETAIL



SYSTEM | MEMS SENSORS

Inertial Measurement Unit (IMU)



Higher performance compared to macroscale counterparts



Low production cost per-device



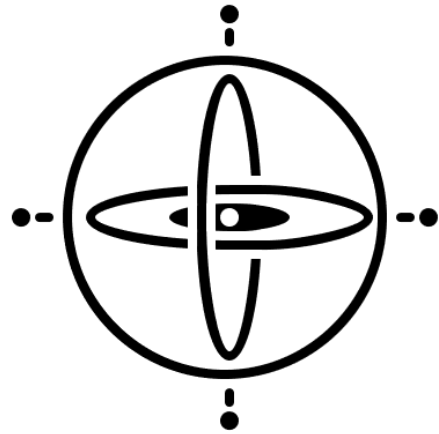
Similar functionality in smaller devices



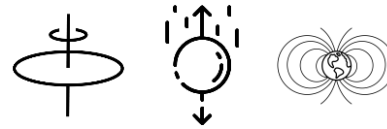
Potential: Minimized sensors, actuators together with IC on same silicon



SOLUTIONS | PURPOSE OF IMU



Measures

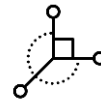


Angular velocity

Acceleration

Magnetic field

Orientation



Position estimation



SOLUTIONS | PURPOSE OF IMU

Measures

Angular velocity

Acceleration

Magnetic field

Obtain raw data

Gyroscope

Accelerometer

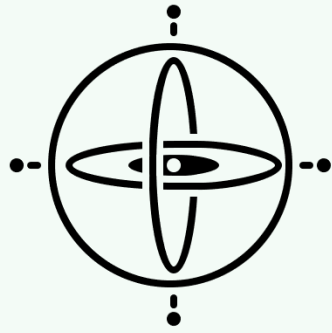
Magnetometer

Orientation

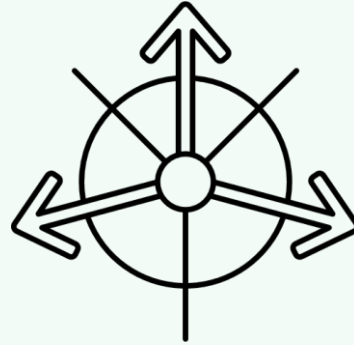
Position estimation



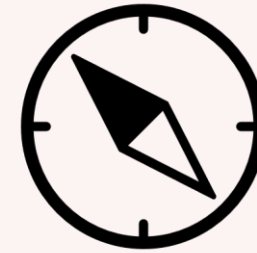
SOLUTIONS | SENSOR TYPES



Gyroscope



Accelerometer



Magnetometer

6 Degrees of Freedom (DoF)

9 DoF

SYSTEM | OVERVIEW



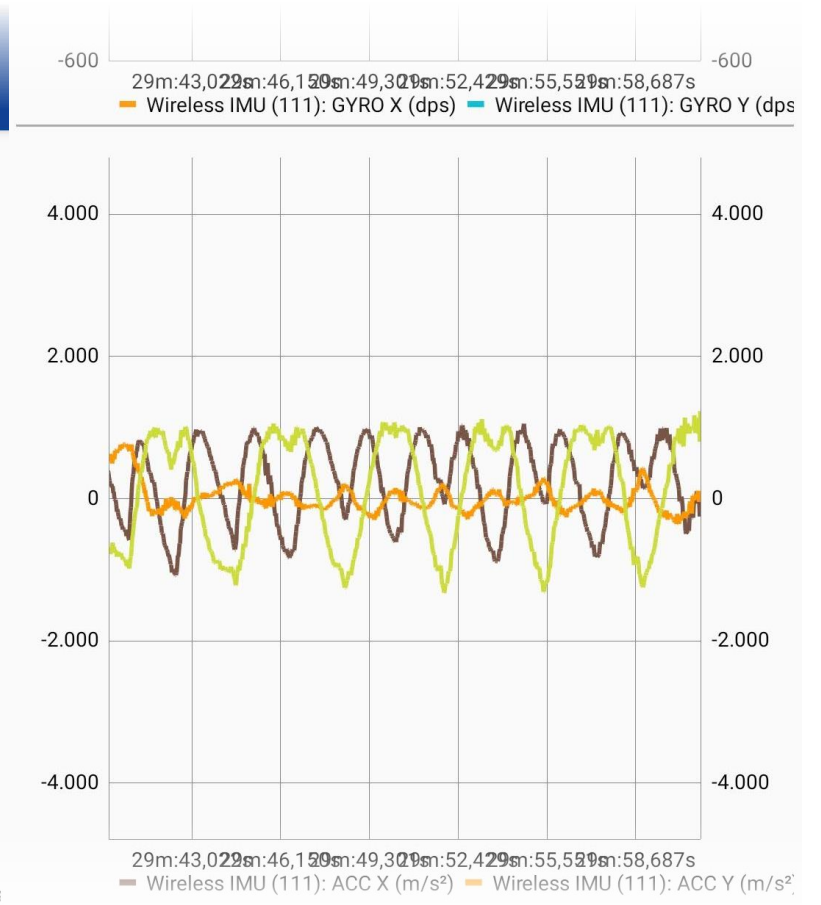
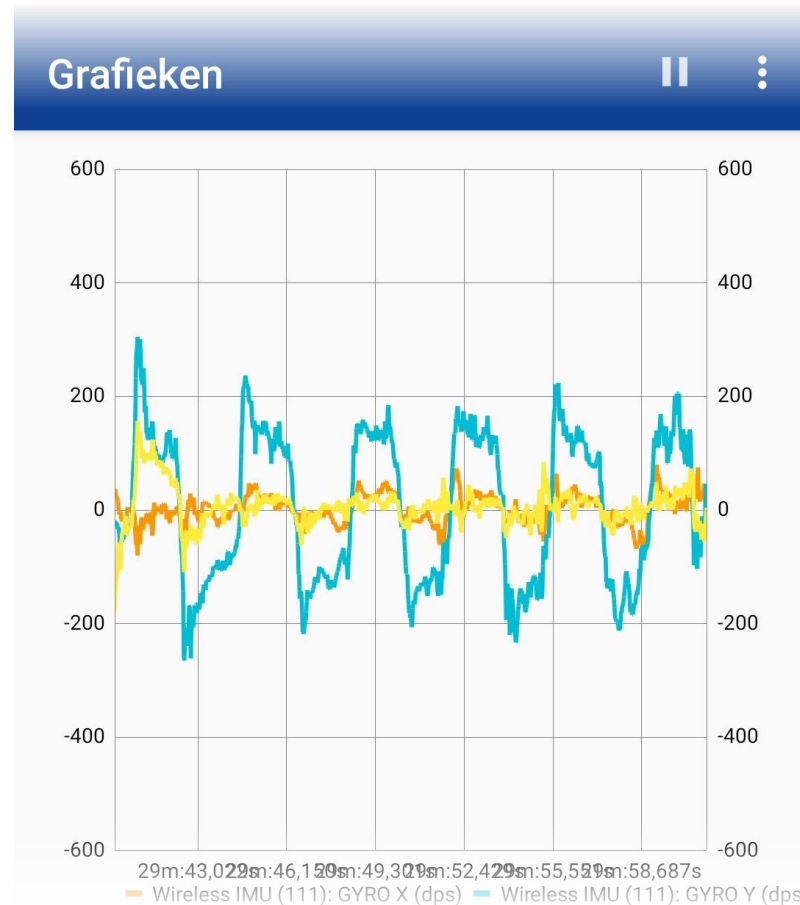
Motion sensors
(IMUs)



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

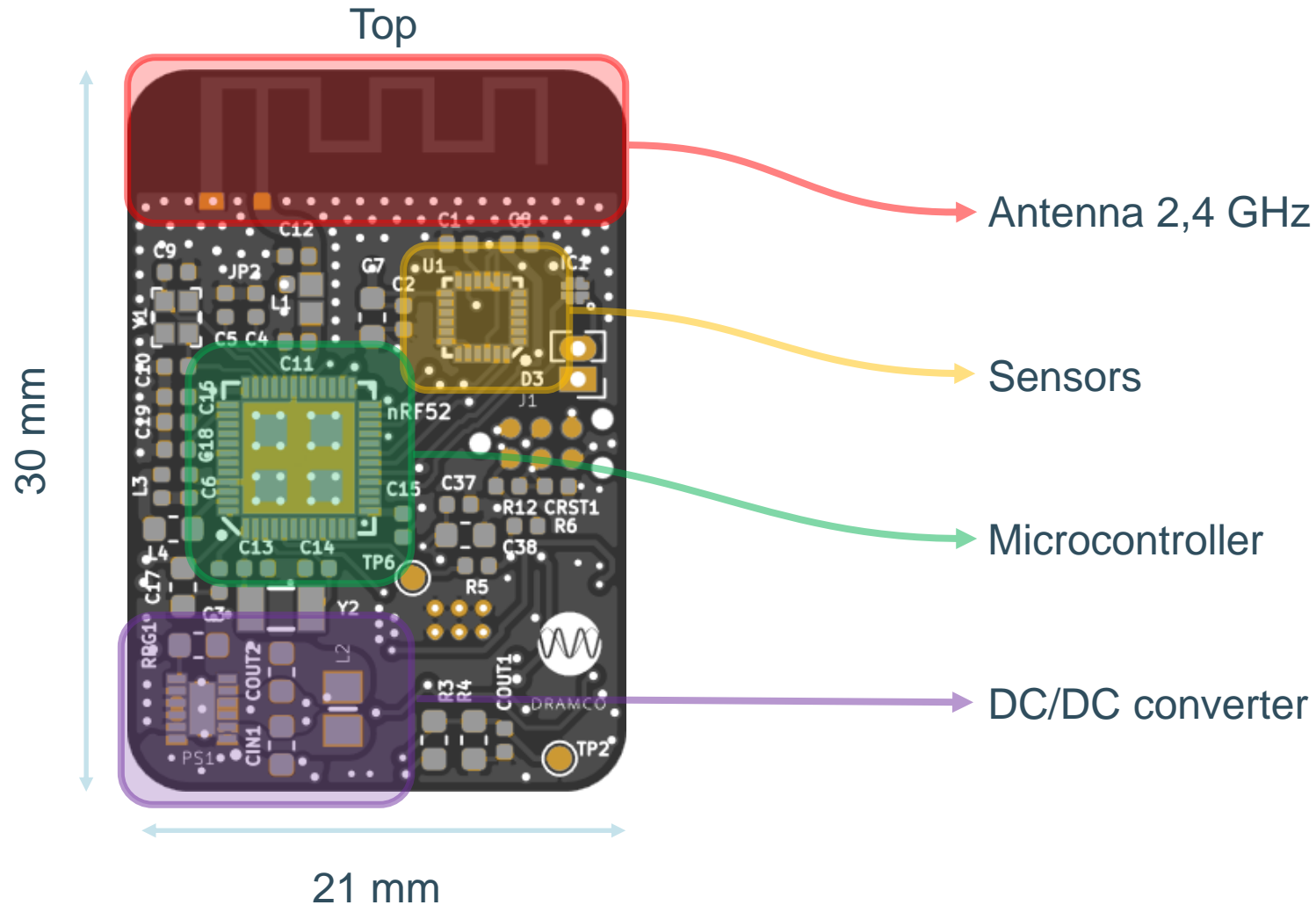
(Store calibration params in flash memory)



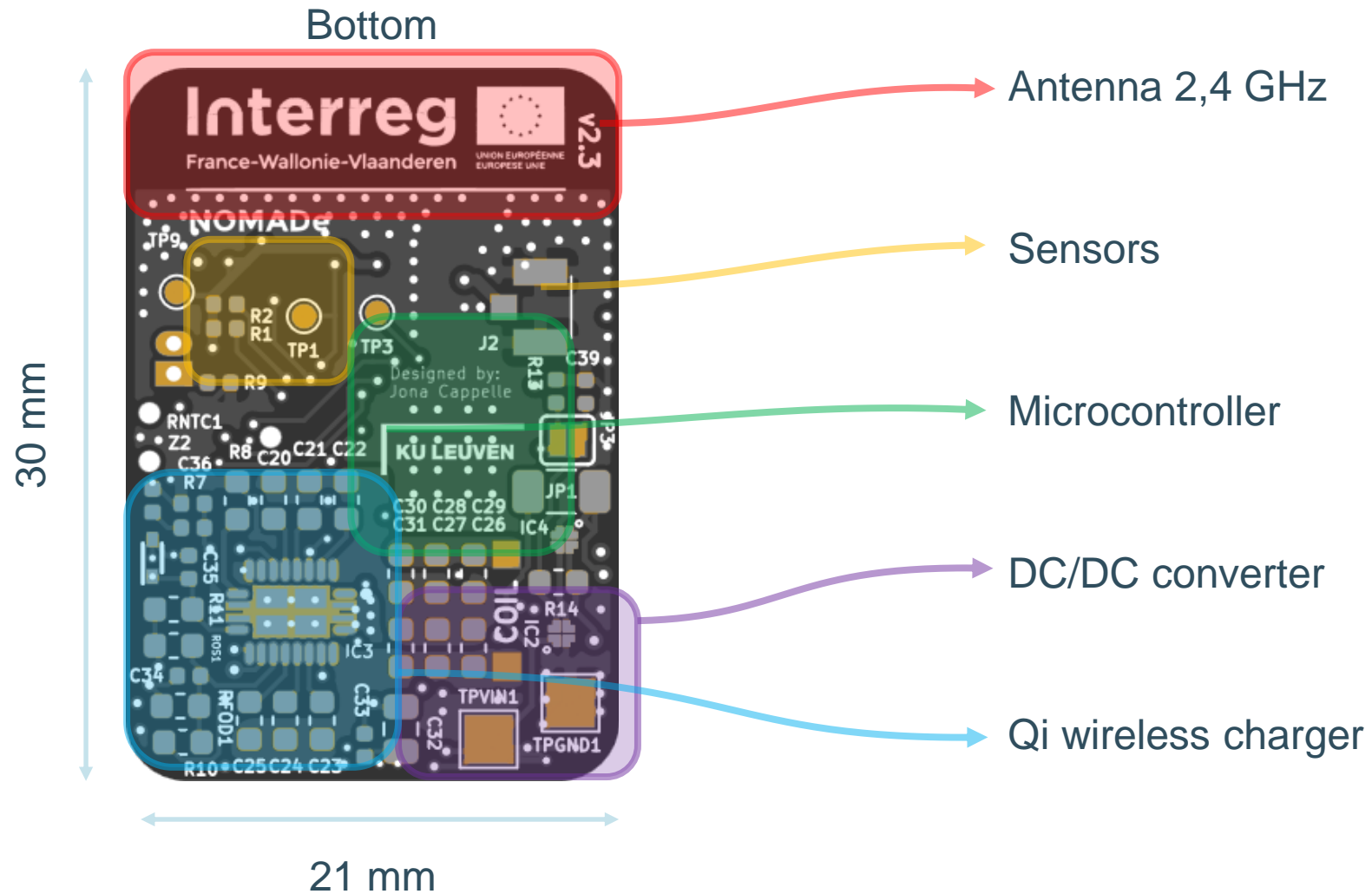
Remote update

(Via smartphone over BLE)

SYSTEM | CIRCUIT ANALYSIS



SYSTEM | CIRCUIT ANALYSIS



BLOCK DIAGRAM

ICM-20948 TDK Invensense

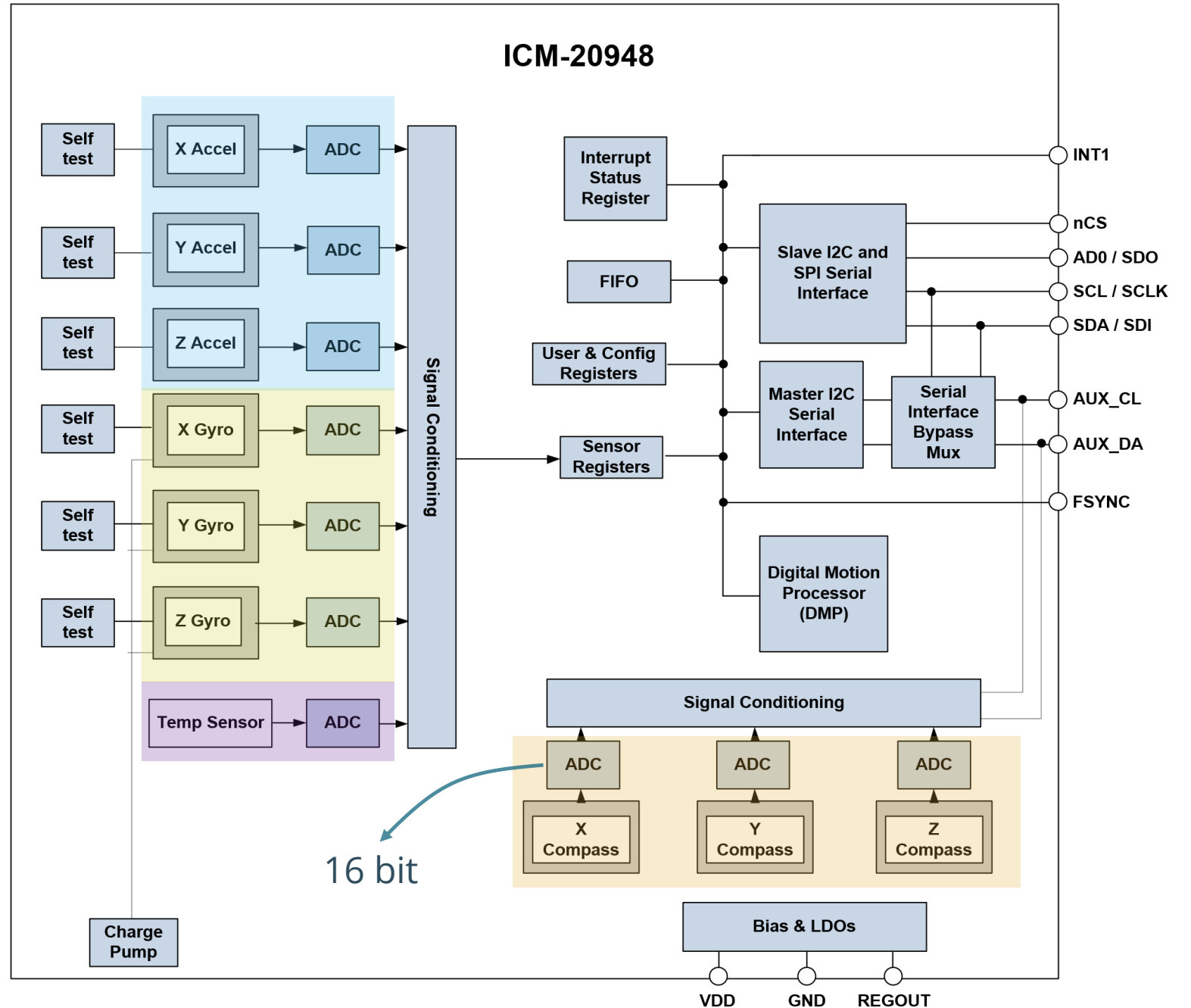
Sensors

Accelerometer [m/s²]

Gyroscope [dps]

Temperature [°C - F]

Compass [μT]



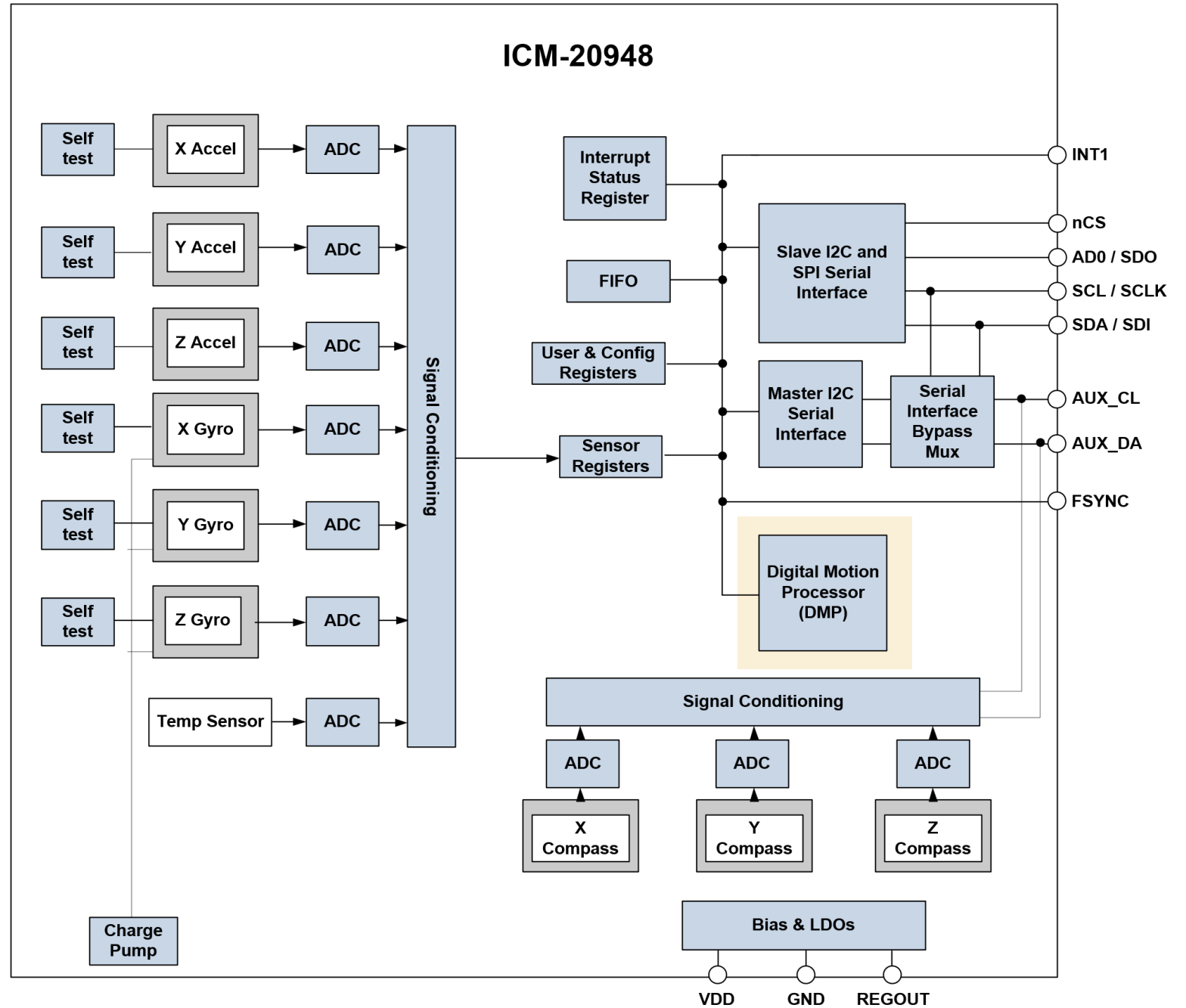
BLOCK DIAGRAM

ICM-20948 TDK Invensense

Sensor Fusion

Digital Motion Processor
(DMP)

RAW data → Orientation
(3 sensor types)

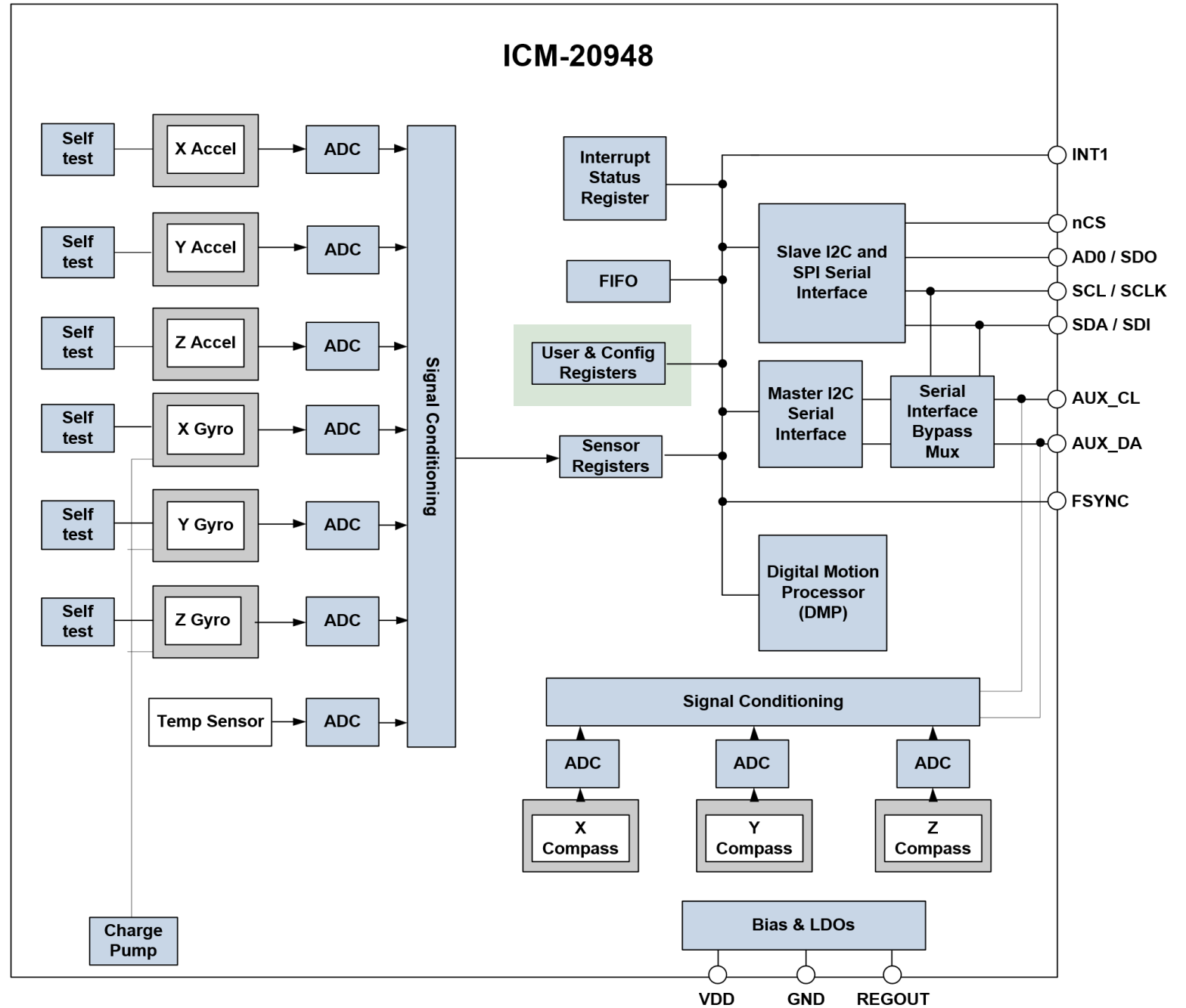


BLOCK DIAGRAM

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 $\pm 4900 \mu T$

Output Data Rate (ODR)

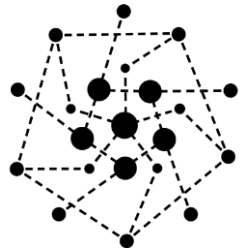
Gyroscope $\pm 4 \text{ Hz} - 0,5 \text{ kHz}$

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

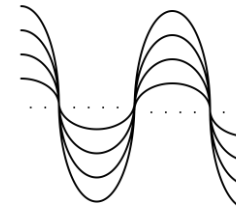
Quaternions / Euler angles - 9 DoF



Gyroscope (dps)

Accelerometer (mg)

Magnetometer (μT)



50 Hz

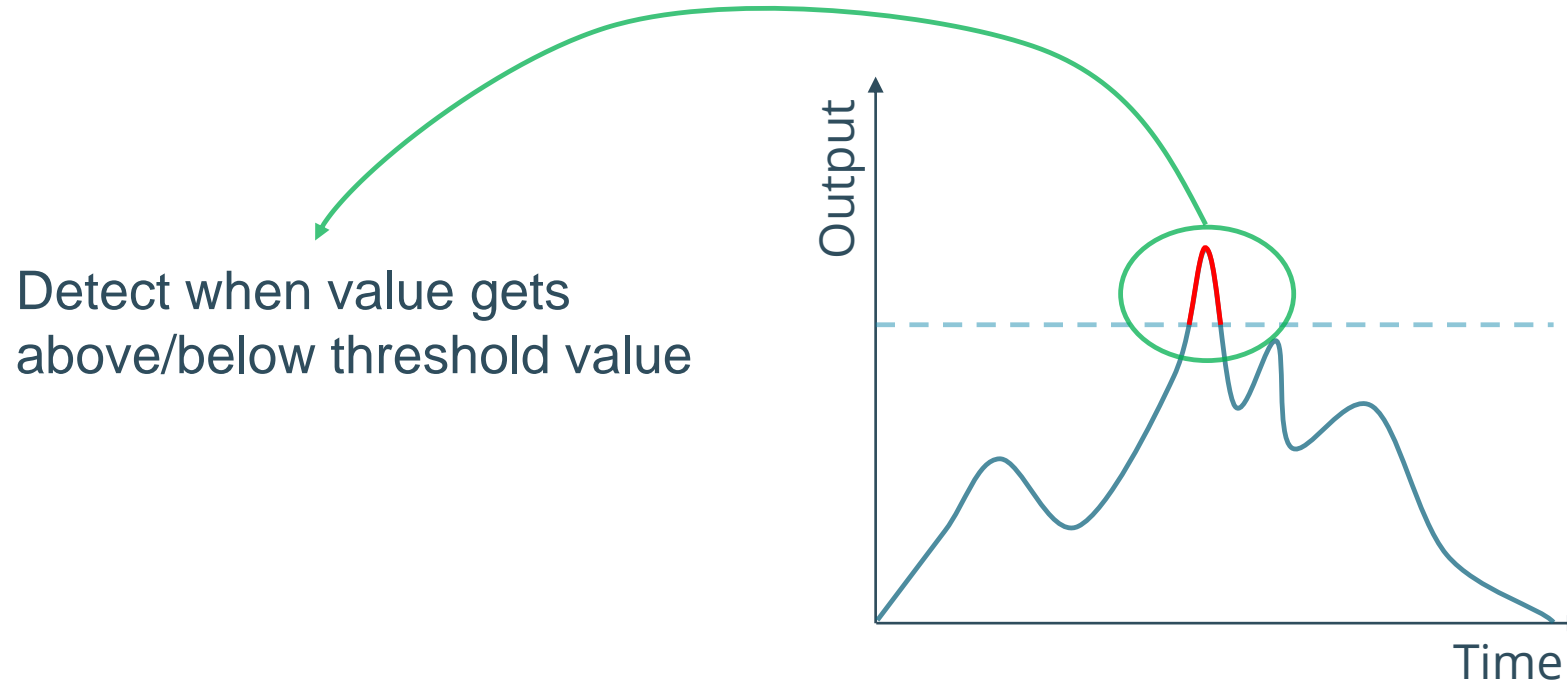
100 Hz

SYSTEM | POST PROCESSING

Examples:

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

- Threshold detection algorithm



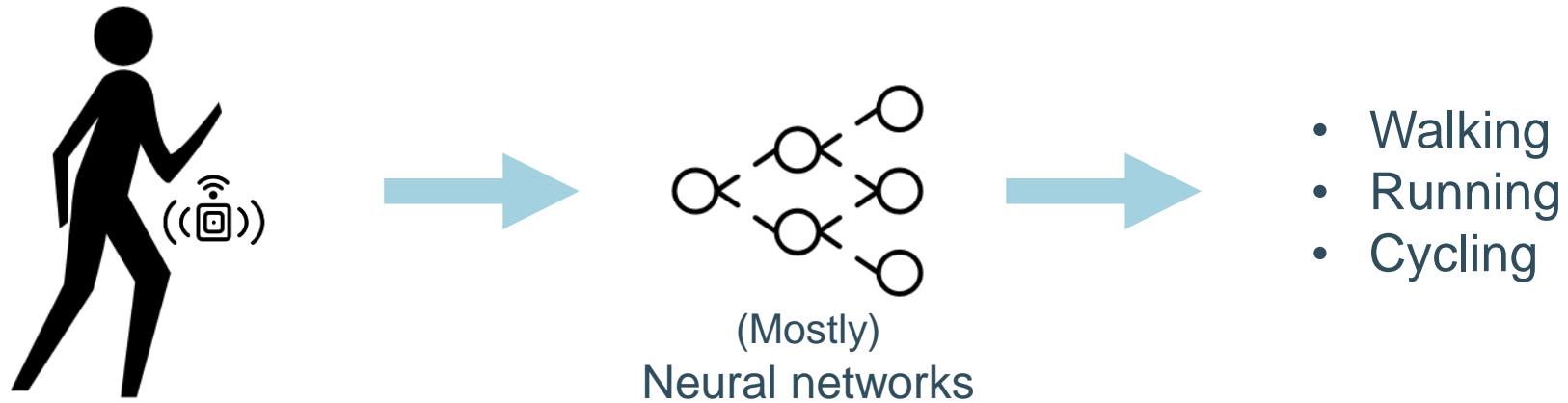
- Recognising patterns with machine learning

SYSTEM | POST PROCESSING

Examples:

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

- Threshold detection algorithm
- Recognising patterns with machine learning



- Detecting entropy

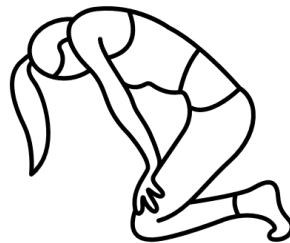
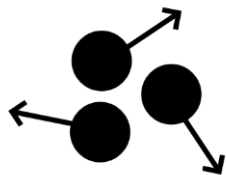
SYSTEM | POST PROCESSING

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



INTRODUCTION
POSSIBLE SOLUTIONS
RESULTING SYSTEM
CHALLENGES
CONCLUSION

CHALLENGES | WHICH?

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

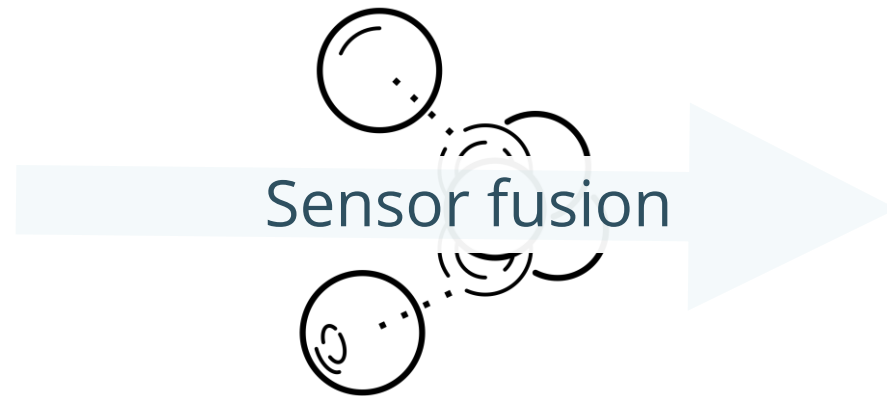
CHALLENGES | WHICH?

- **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

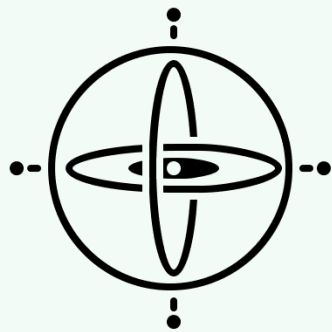
How an object is placed in space
Refer to a reference placement

CHALLENGES | MOVEMENT TRACKING WITH IMU

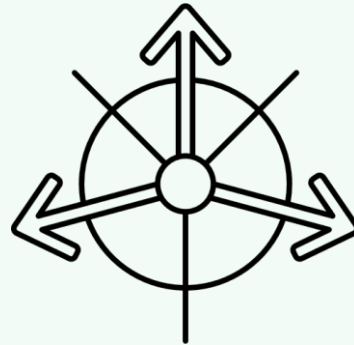
Integration of angular velocities
(small accumulating error)

Correction for drift
roll + pitch

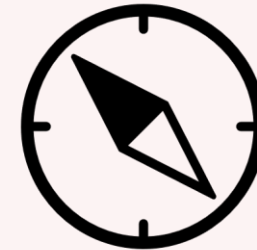
Correction for drift
yaw



Gyroscope



Accelerometer



Magnetometer

6 Degrees of Freedom (DoF)

9 DoF

CHALLENGES | WHICH?

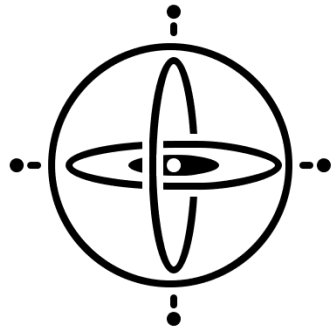
- Movement tracking with IMU
- **Calibration**
- Synchronization
- Power consumption

CHALLENGES | CALIBRATION

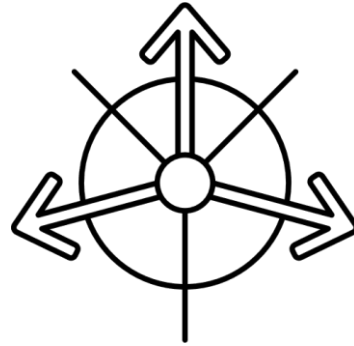


To ensure the sensor performs according to the specification
and to provide meaning to the electrical output

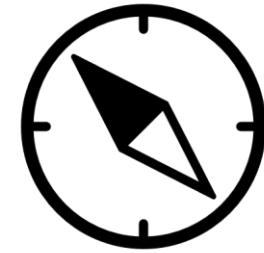
CHALLENGES | CALIBRATION ERRORS



Offset + Scale



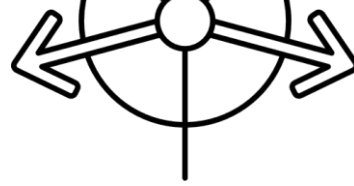
Offset + Scale



Hard + Soft iron distortions



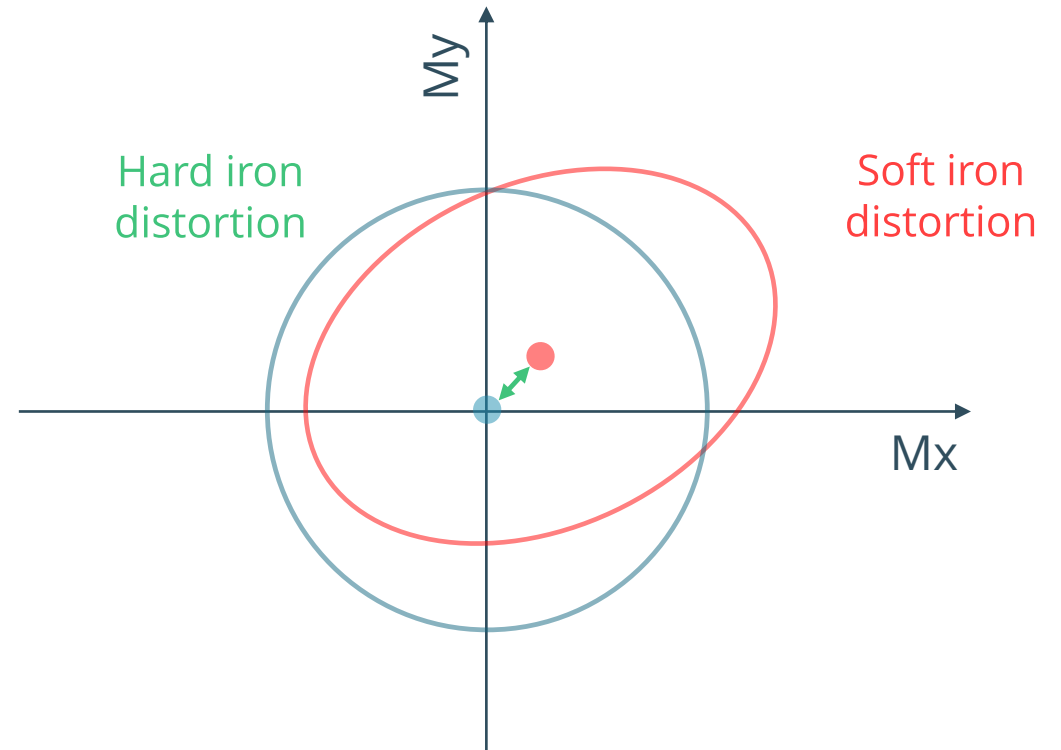
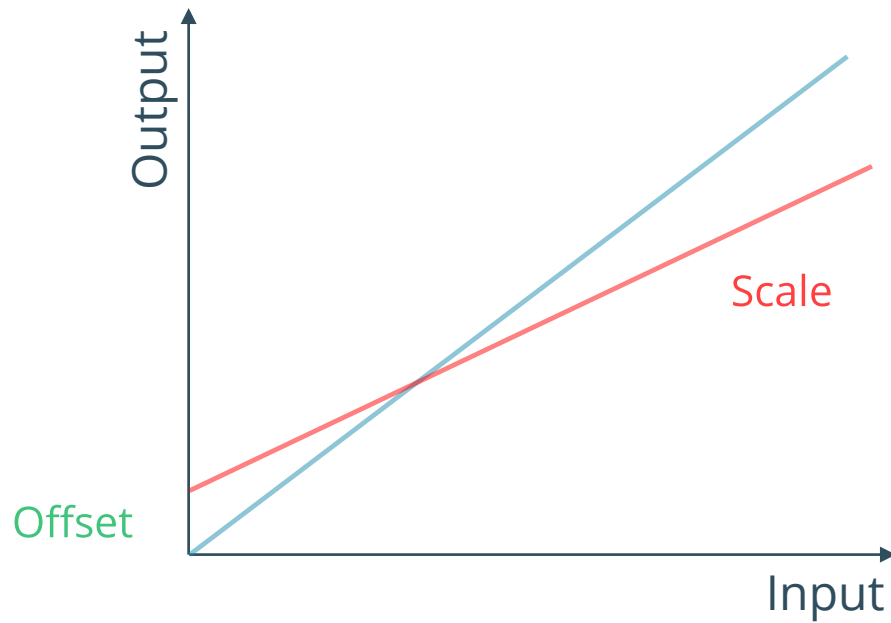
Offset + Scale



Offset + Scale



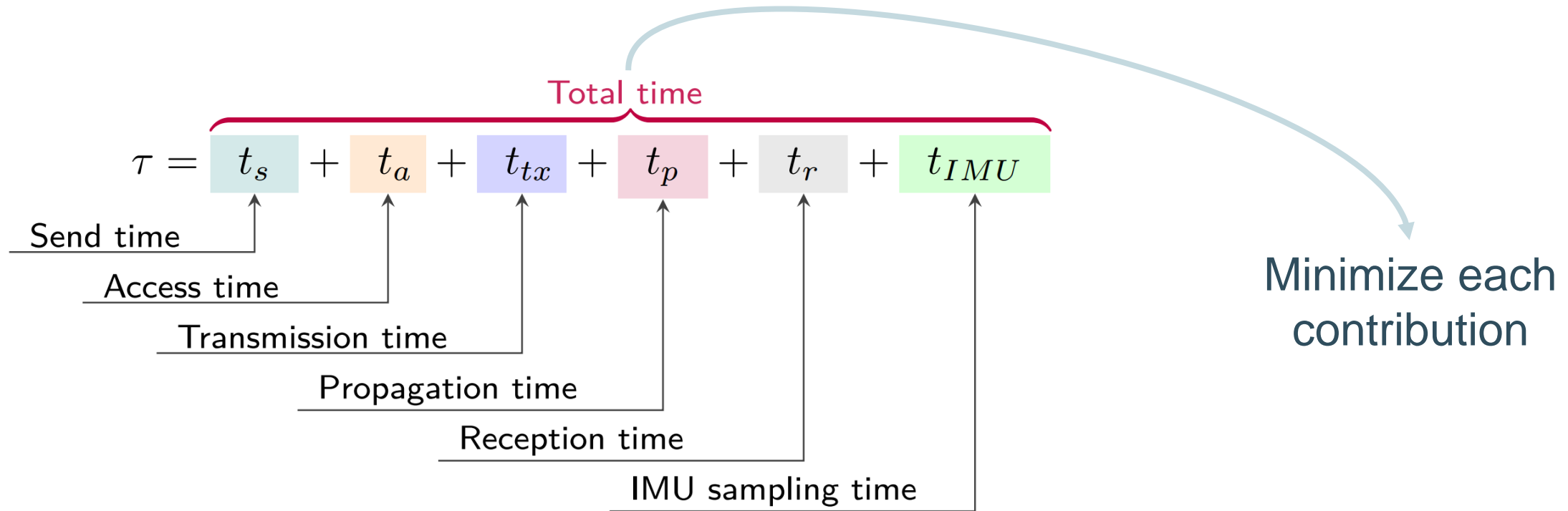
Hard + Soft iron distortions



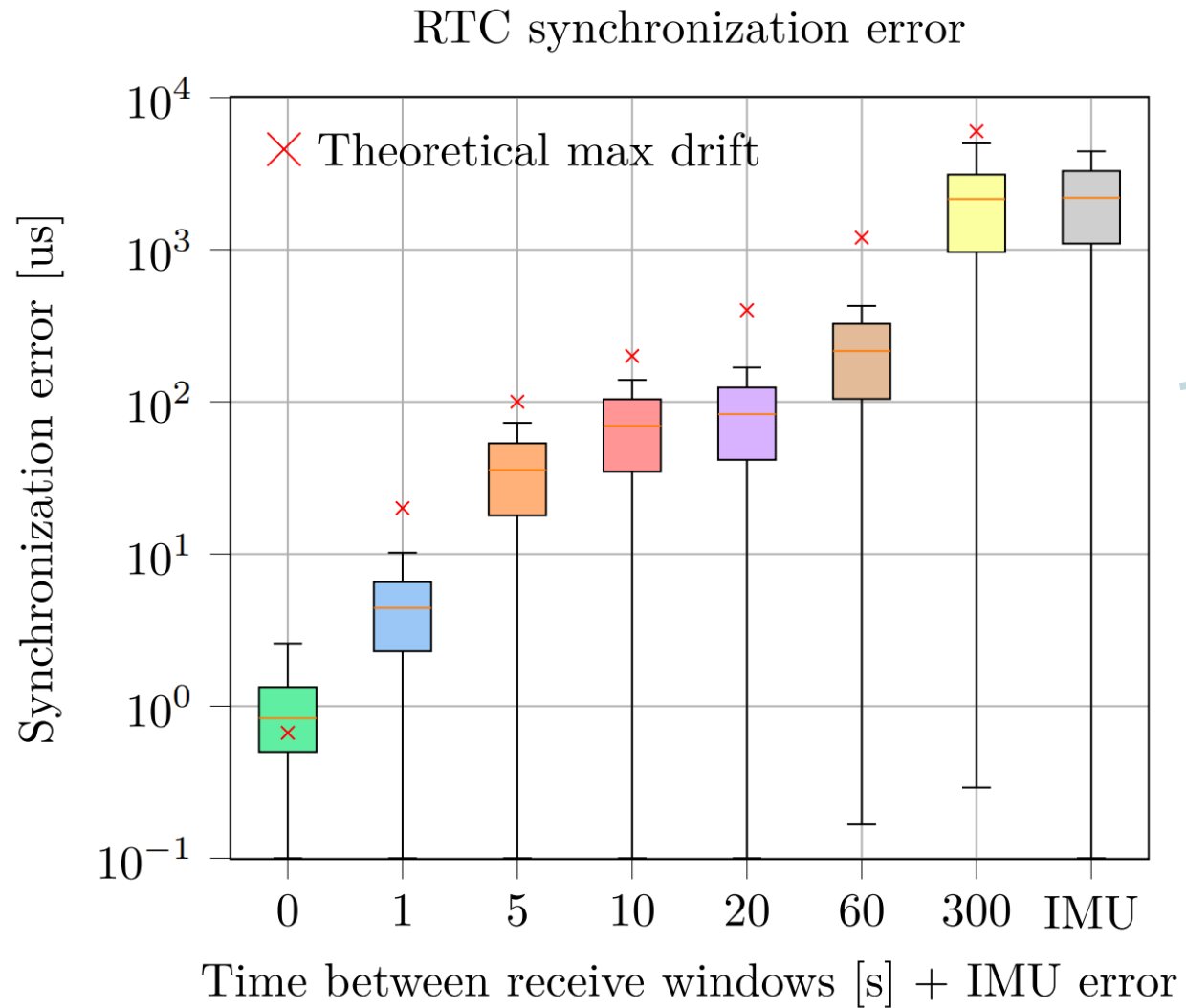
CHALLENGES | WHICH?

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

CHALLENGES | SYNCHRONIZATION



CHALLENGES | SYNCHRONIZATION



Microsecond level wireless synchronization accuracy over BLE link

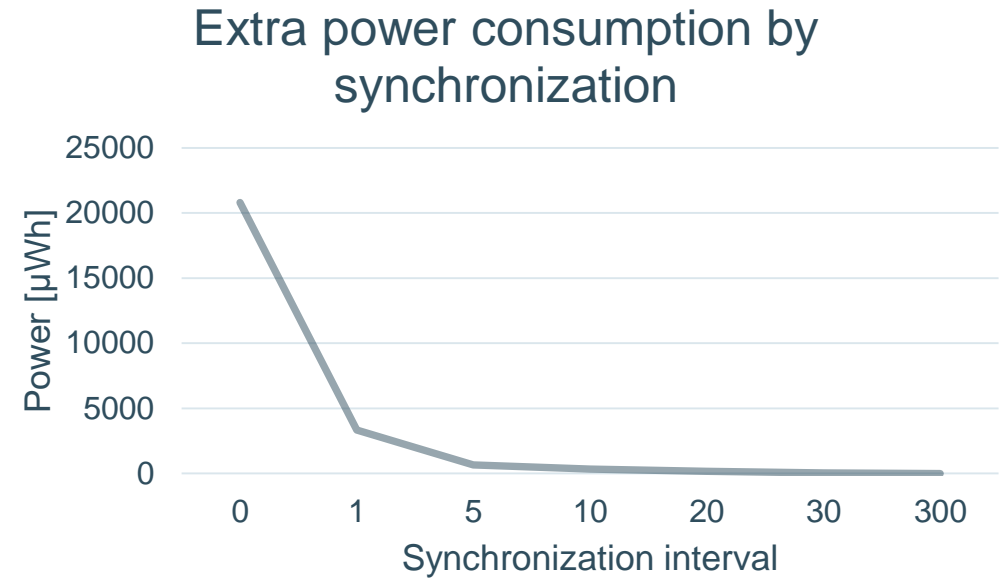
CHALLENGES | WHICH?

- 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
POSSIBLE SOLUTIONS
RESULTING SYSTEM
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.**

Free 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>

PUBLICATIONS WITH OUR SENSOR SYSTEM

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



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

De oorsprong van neuro-musculo-skeletale aandoeningen (NMSA) is multifactorieel. De professionele risicofactoren zijn gedefinieerd. 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 & Artificialle Intelligentie (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.

Bewegingssensoren & NOMADe-applicatie

Een contactloze multi-sensoroplossing 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[®]

Een virtuele versie van de zogenaamde "Didren" klinische test om de cervicale mobiliteit te beoordelen met behulp van een richtsysteem met laserstraal, waarbij de laserstraal wordt bewogen door rotaties van de nek (Hage & Ancemay, 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 gezondheidsverliefers te promoten: een pilootstudie bestaande uit 3 videomodules:

- Evaluatie en diagnostische triage van een patiënt met lage rugklachten
- Aanpak van een patiënt met lage rugklachten
- 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