IoCT-CARE: Internet of Cognitive Things for Personalized Healthcare

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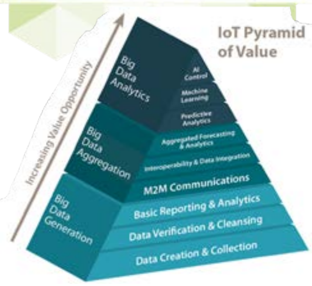
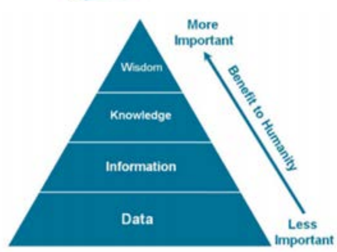
Turun yliopisto University of Turku | UCI University of California, Irvine | TU WIEN Technische Universität Wien Vienna University of Technology

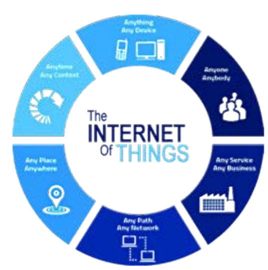
SBCCI Aug 31, 2018

Internet-of-Things

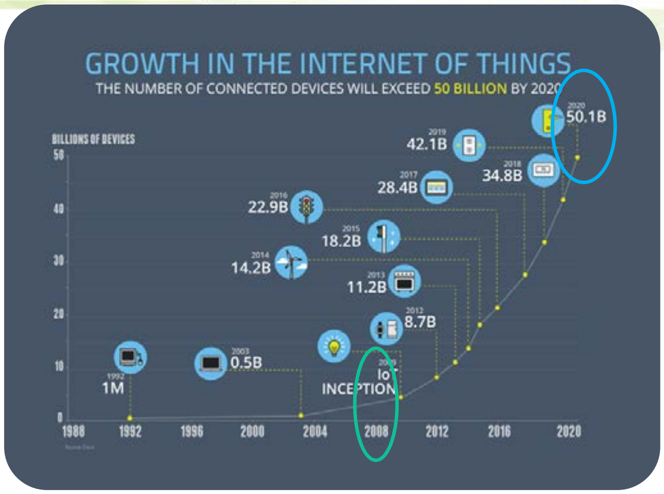
- **Today's Internet** is the "**Internet of People**".
  - Mainly **connecting applications** used by people.
- IoT is the **network of things**, with device **identification**, **embedded intelligence**, and **sensing** and **acting** capabilities, **connecting people and things over the Internet**.







IoT Connectivity



+50 Billion device connected to the Internet by 2020!

#devices connected to the Internet > #people on Earth

Source: Cisco

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Outline

- **Internet-of-Things (IoT)**
  - IoT in Healthcare
  - HiCH Architecture
- **Healthcare IoT Case Studies**
  - 1. IoT-based Early Warning Score (EWS) in Everyday Settings
  - 2. Smart Pain Assessment Tool Based on IoT
  - 3. Family Centered Monitoring in Maternity Care
- **Future Research Directions**

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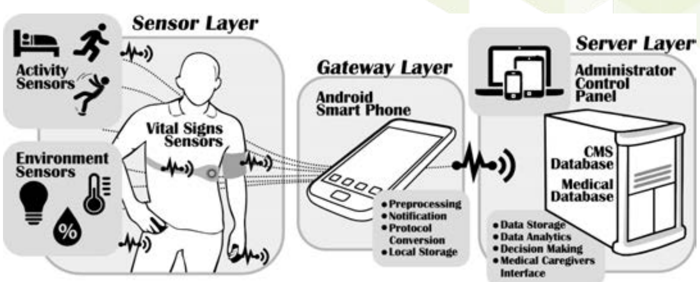
Internet of Things in Healthcare



- **IoT** and **wearable** technologies to:
  - **Continuously track patients**
  - **Personalization**
  - **Predict health status**
  - **Self-management**
  - **Prevention & Smart intervention**

- The IoT paradigm **holds significant promises** in **healthcare** domain.
  - ↑ **access to care**
  - ↓ **healthcare costs**

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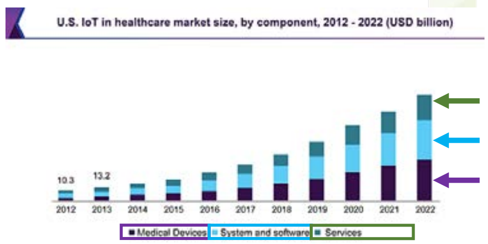
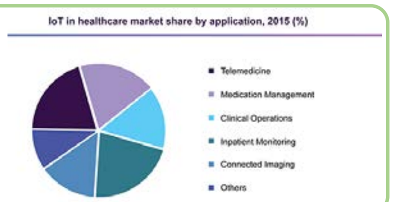
IoT in Healthcare Market *Size, Share, and Trend*



Global IoT in **healthcare market size** $98.4B in **2016**!

Source: GrandViewResearch, available at http://www.grandviewresearch.com/industry-analysis/internet-of-things-iot-healthcare-market.



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Editorial

Internet-of-Things and big data for smarter healthcare: From device to architecture, applications and analytics

Farshad Firouzi [a], Amir M. Rahmani [b,c], K. Mankodiya [d], M. Badaroglu [e], G.V. Merrett [f], P. Wong [g], Bahar Farahani [h]

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[b] University of California, Irvine, USA
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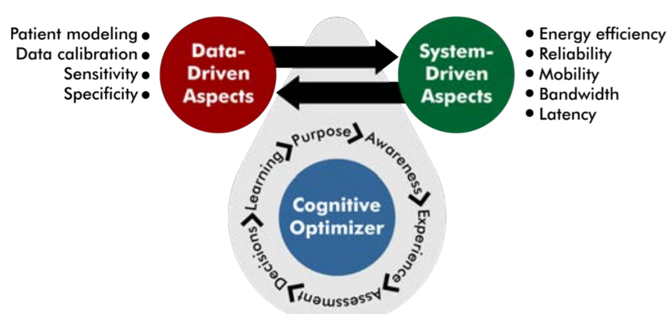
[f] University of Southampton, UK
[g] Stanford University, USA
[h] Department of Electrical and Computer Engineering, University of Tehran, Iran

Quality of Experience Management

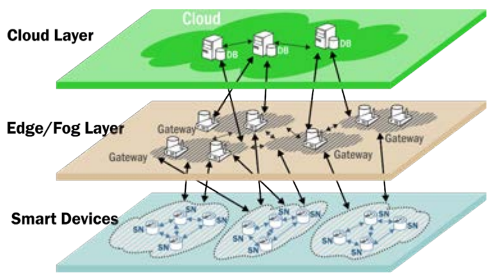
- IoT-based health monitoring applications need to provide a high level of quality attributes.



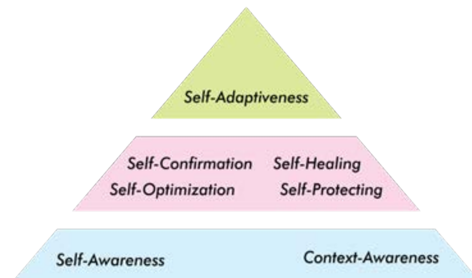
Emerging Concepts

- We leverage two concepts to achieve high quality attributes during health monitoring

Fog/Edge computing

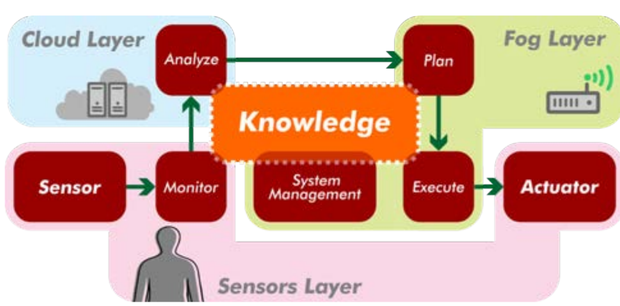


Computational self-awareness

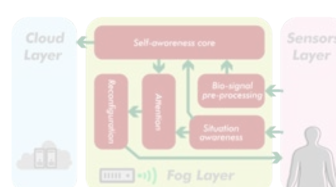


Proposed Architectures

HiCH: a hierarchical computing architecture for healthcare IoT



Self-Awareness in Remote Health Monitoring Systems using Wearable Electronics

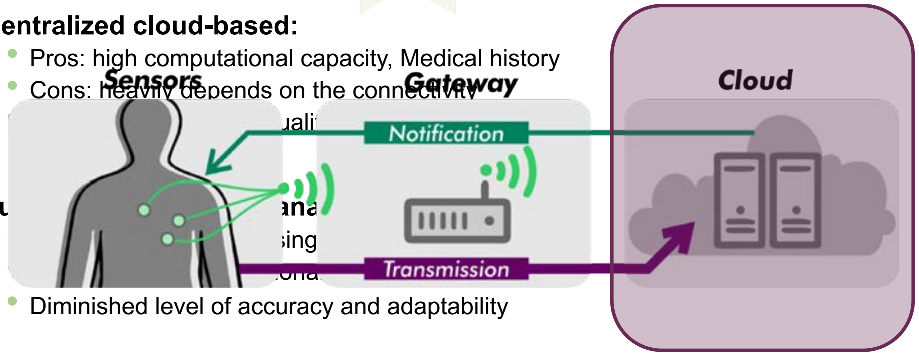


A hierarchical computing architecture to provide a high level of quality in attributes such as availability and punctuality.

Iman Azimi, Arman Anzanpour, Amir M. Rahmani, Tapio Pahikkala, Marco Levorato, Pasi Liljeberg, and Nikil Dutt, "HiCH: Hierarchical Fog-assisted Computing Architecture for Healthcare IoT," In Proc. EMSOFT (ESWEEK), 2017.

Conventional Architecture

- **Centralized cloud-based:**
  - Pros: high computational capacity, Medical history
  - Cons: heavily depends on the connectivity



- **Fu**
  - Diminished level of accuracy and adaptability

- **Patient monitoring** requires a high level of accessibility, robustness and accuracy, so such architectures are inappropriate.

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Our Solution

HiCH: a **hierarchical computing architecture** for healthcare IoT

Our Contributions

- A hierarchical computing architecture to partition the existing machine learning methods.
- A customized IBM's MAPE-K model for the proposed architecture.
- A closed-loop management technique featuring an adaptive data transmission solution w.r.t patient's conditions.
- A full system implementation for continuous health monitoring case study focusing on arrhythmia detection for patients suffering from CVDs.

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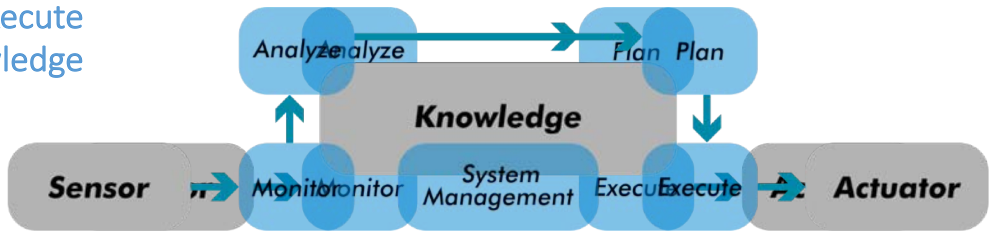
IBM MAPE-K Model

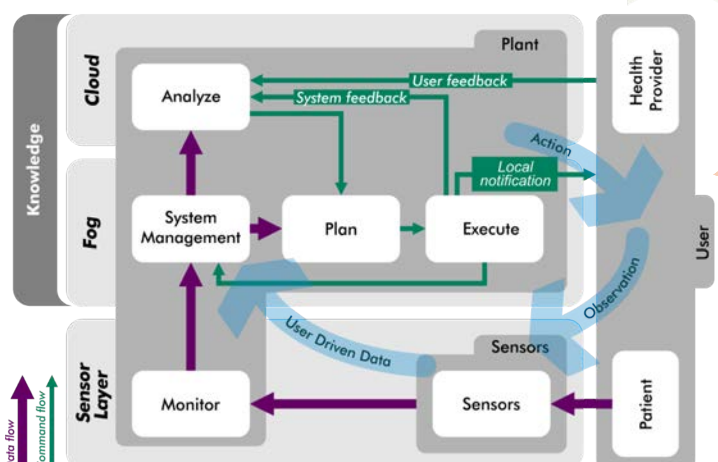
Monitor
Analyze
Plan
Execute
Knowledge

- We propose HiCH using a computing model for knowledge.



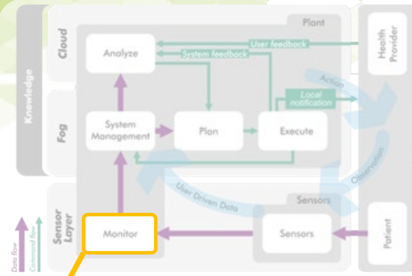
Enhanced MAPE-K model
introducing a **System Management** component

System Architecture

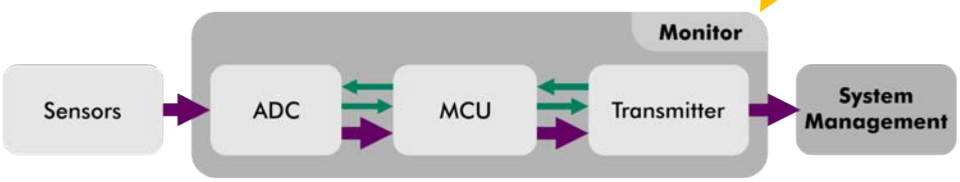


- We map the heavy training procedures in the cloud while periodically outsourcing the trained hypothesis to the fog nodes.
- The knowledge at the edge is used to enhance resource management via closed-loop control.

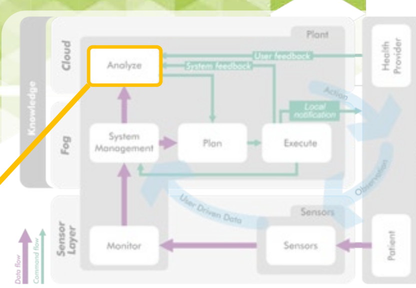
Computing Components: Monitor



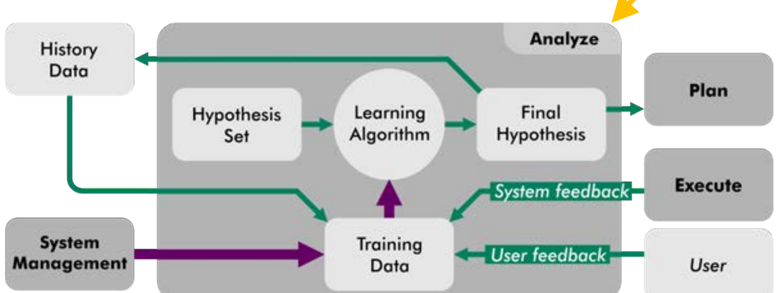
- Monitor component observes the patient and collects the data from the sensor node.



Computing Components: Analyze

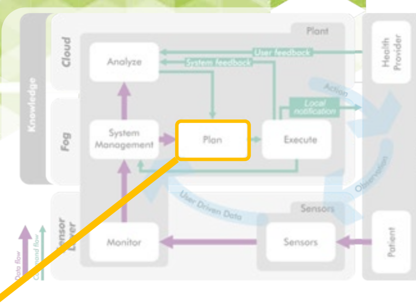


- It models situations via data analytics
- The classifier is created using training data
- The classifier will be sent to Plan located at the edge

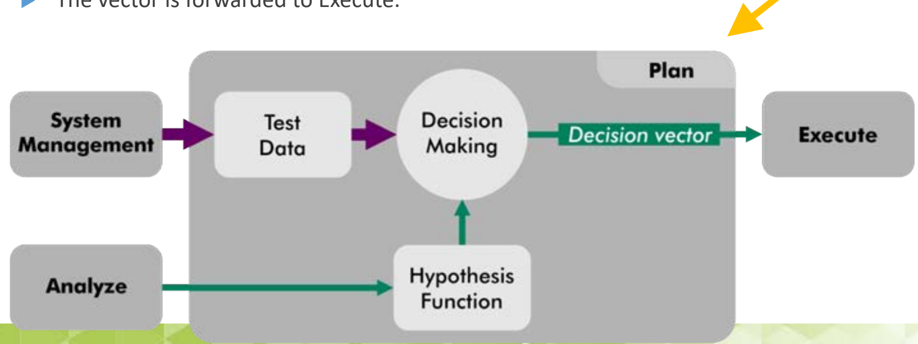


- Some machine learning algorithms can be chosen:
- We consider a linear machine learning method (linear SVM) for our design.
- Nonlinear classifiers may be fitted to HiCH depending on time and space complexity.
- Some nonlinear classifiers are inappropriate (e.g., instance-based learning methods).

Computing Components: Plan



- It selects the procedure for the system.
- A decision vector is generated that indicates the current patient's condition.
- The vector is forwarded to Execute.



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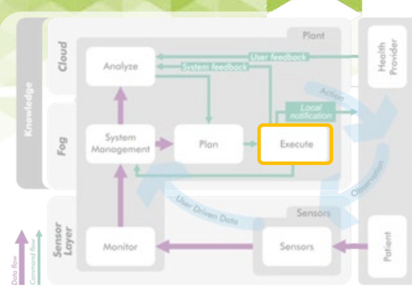
Computing Components: Execute



- It provides the changes in the system.
- It updates:
  - **System Management:** to apply changes w.r.t. the patient condition.
  - **Users:** to locally notify them about the patient condition.
  - **Analyze:** to provide a system feedback.

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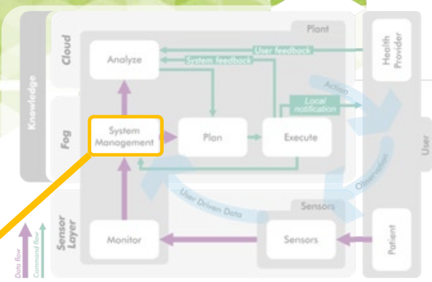
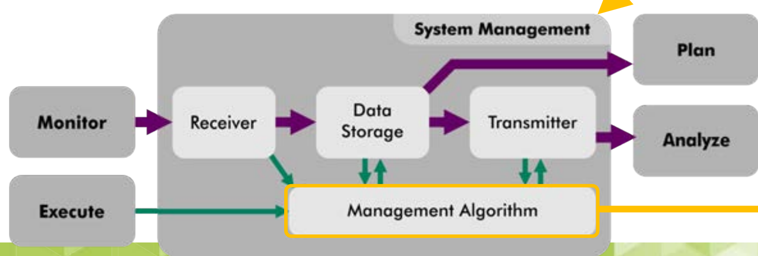
Computing Components:
System Management

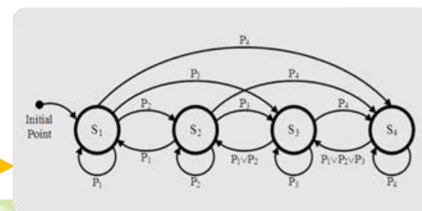


- It performs the data transmission control.
- It implements required data reduction for the transmission to the cloud.
- It includes a Management Algorithm modeled with a finite-state machine (FSM).



System's states: S1, S2, S3, S4

Patient's states: P1, P2, P3, P4



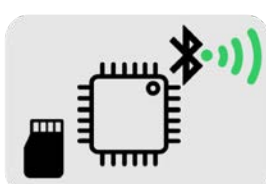
Demonstration and Evaluation
System Setup

Data:
Long-Term ST Database on PhysioBank for Arrhythmia patients

Sensor Node:
Emulated ECG wireless sensor node using PhysioBank data on SD-card + Atmega328P MCU + RN-42 Bluetooth module

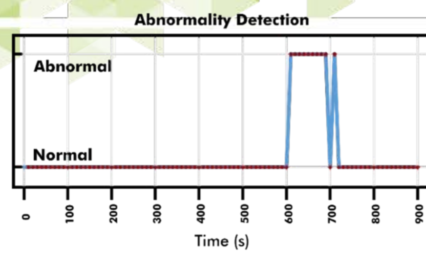
Gateway:
- Jetson TK-1
Quad-core cortex A15
2.33GHz CPU
192 CUDA cores & 2GB RAM
- HP Compaq 8200
Quad-core Core-i3
3.1GHz CPU
16GB RAM

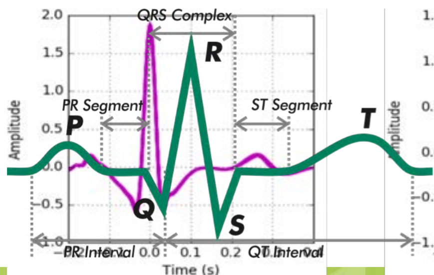
Cloud:
Linode VPS
2 x 2.5GHz intel Xeon CPUs
4G RAM



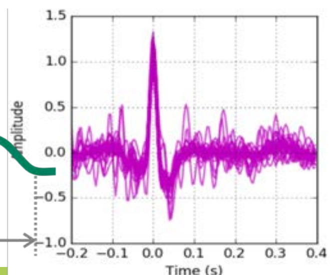
Demonstration and Evaluation

- **Arrhythmia detection in ECG monitoring for patients suffering from CVDs**
- ECG cycles are segmented based on RR peaks.
- 5 features in the temporal domain are extracted.
- A binary classification (normal vs abnormal) is defined.





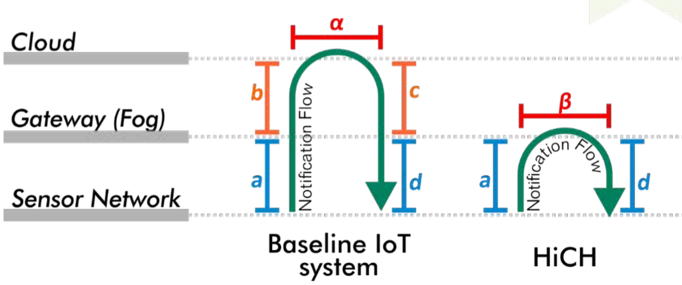
Normal ECG



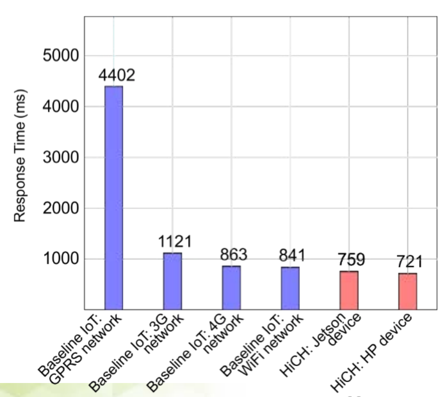
ECG with arrhythmia

Demonstration and Evaluation

Response Time



- a, b, c, d: Data transmission time between the sensor node, the gateway device and the cloud server
- α, β: Computation time for data analytics in the cloud and in the fog



Demonstration and Evaluation
Bandwidth Utilization and Storage

- Data transmission and data storage in the cloud are reduced.

Q	Data to be transferred to the cloud (KB)	Data de-scription (KB)	TCP overhead (KB)	Total trafic (KB)
1	439	29	13	481
2	879	29	25	933
3	1318	29	37	1384
4	1756	29	49	1836
5	2197	29	61	2287
6	2636	29	73	2738

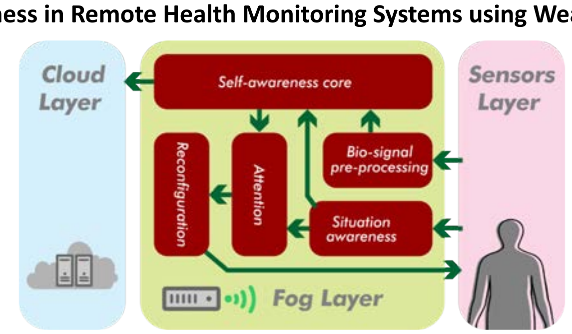
Data trafic for 1 hour monitoring with different Q

Q	Data in normal cond. (KB)	Data in abnormal cond. (KB)	Data stored in the cloud (KB)	Reduction in data size
1	406	355	761	71 %
2	787	355	1142	57 %
3	1167	355	1522	43 %
4	1549	355	1904	29 %
5	1929	355	2284	14 %
6	2310	355	2665	0 %

Data storage for 1 hour monitoring with different Q

Proposed Architectures

Self-Awareness in Remote Health Monitoring Systems using Wearable Electronics



HiCH: a hierarchical computing architecture for healthcare IoT

A self-aware health monitoring architecture to enable intelligent decision making as well as optimizing energy efficiency.

Arman Anzanpour, Iman Azimi, Maximilian Götzinger, Amir M. Rahmani, Nima TaheriNejad, Pasi Liljeberg, Axel Jantsch, and Nikil Dutt, "Self-Awareness in Remote Health Monitoring Systems using Wearable Electronics", In Proc. DATE, 2017.

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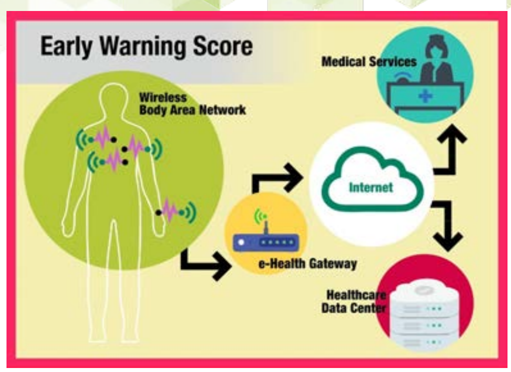
❶ IoT-based Early Warning Score Everyday Settings

IoCT-CARE: Internet of Cognitive Things for Personalized Healthcare, jointly funded by **Academy of Finland**, **TEKES**, and **National Science Foundation (NSF)**
04/2017-03/2019

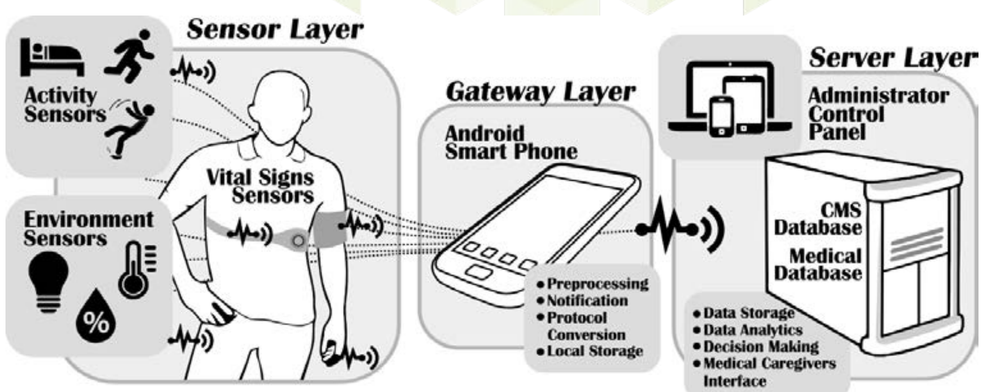


Early Warning Score (EWS)

- **Early Warning Score** is a method to detect the **deterioration** of a patient's condition
  - **24** hours prior to serious impacts
- Currently done **manually** in **clinical settings**

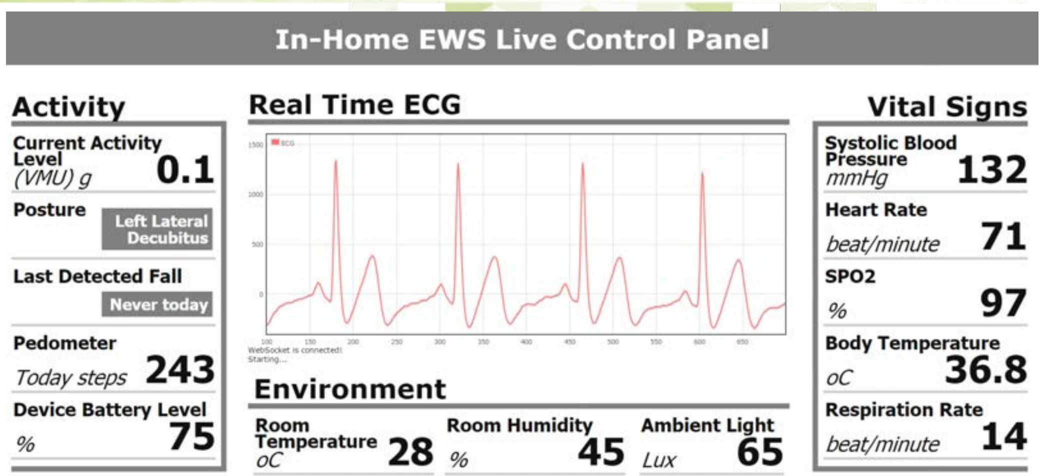
Physiological parameters	3	2	1	0	1	2	3
Respiration rate	≤8		9-10	12-20		21-24	≥25
Oxygen saturation	≤91	92-93	94-95	≥96			
Any supplemental oxygen		Yes		No			
Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1	
Systolic BP	≤90	91-100	101-110	111-219			≥220
Heart rate	≤40		41-50	51-90	91-110	111-130	≥131
Level of consciousness				A			V,P or U

IoT-based In-Home EWS System



Iman Azimi, Arman Anzanpour, **Amir M. Rahmani**, Pasi Liljeberg, and Hannu Tenhunen, "Self-Aware Early Warning Score System for IoT-Based Personalized Healthcare," International Conference on IoT and Big Data Technologies for HealthCare **(IoTCare'16)**, 2016.

Cloud Server: EWS Control Panel



Maximilian Götzinger, Nima Taherinejad, **Amir M. Rahmani**, Pasi Liljeberg, Axel Jantsch, and Hannu Tenhunen, "Enhancing the Early Warning Score System Using Data Confidence," International Conference on Wireless Mobile Communication and Healthcare **(MobiHealth'16)**, 2016 [Best paper award].

Ongoing research

- Monitor patient with **arrhythmia**
- Integrating in an IoT-enabled **Holter** monitor

Figure: Layout (Top and bottom view, from left to right, respectively

Figure: Prototype (Top and bottom view, from left to right, respectively

ECG, HR, and Activity

SpO2, RR, and Skin Temp

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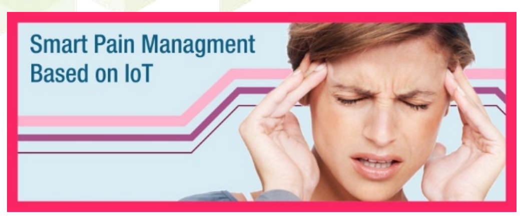
❷ Smart Pain Assessment Tool Based on IoT

PASI: Personalized Pain Assessment System based on IoT, A. Rahmani , **ICT 2023** programme jointly funded by **Academy of Finland** and **TEKES**, UTU Dept. of Future Technologies and Dept. of Nursing Science **Consortium 01/2018-12/2019**

SPA: Smart Pain Assessment Tool Based on Internet-of-Things, A. Rahmani, **ICT 2023** programme jointly funded by Academy of Finland and TEKES, UTU Dept. of Future Technologies and Dept. of Nursing Science **Consortium 01/2015-12/2016**



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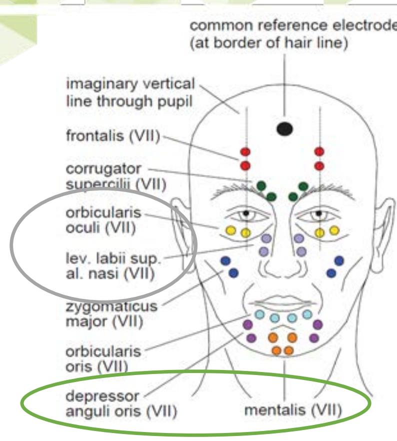
Pain Assessment

- Assessment of pain is difficult when the **ability** of the patient to **communicate** is limited.
  - during critical illness
  - under sedation
  - under anesthesia
  - for infant
- Pain is a highly **subjective** experience

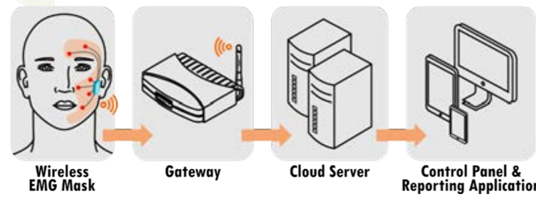
Pain Reflectors

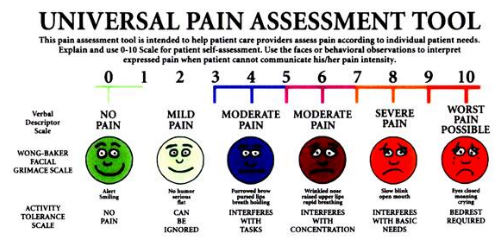
- The activity of **facial muscles** is under **control** of the **facial nerve**.
- The amplitude of frontal muscle activity during **sedation** and **anesthesia** reflects
  - increases during painful stimuli
- Some **physiological** signs can also reflect **autonomic nervous system** activity



Smart pain assessment tool based on IoT

- To provide an automatic **multi-modal** tool to detect and assess pain :
  - **Behavioral**
    - Facial muscle activity (sEMG)
  - **Physiological**
    - Heart rate
    - Heart rate variability
    - Electrodermal activity
    - Breathing rate





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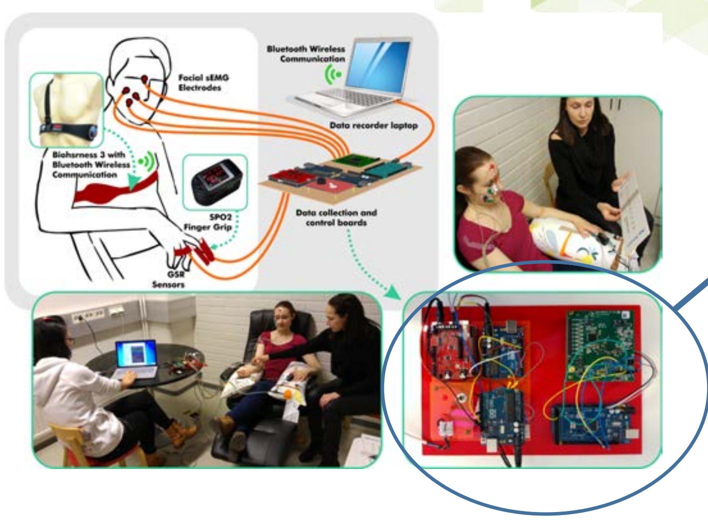
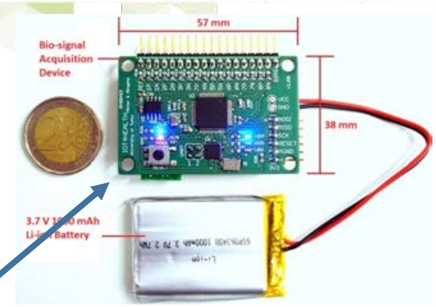
First Pain-related Bio-signal Acquisition device





Victor Kathan Sarker, Mingzhe Jiang, Tuan Nguyen Gia, Arman Anzanpour, **Amir M. Rahmani**, and Pasi Liljeberg, "Portable Multipurpose Bio-signal Acquisition and Wireless Streaming Device for Wearables," IEEE Sensors Applications Symposium (SAS'17), 2017.

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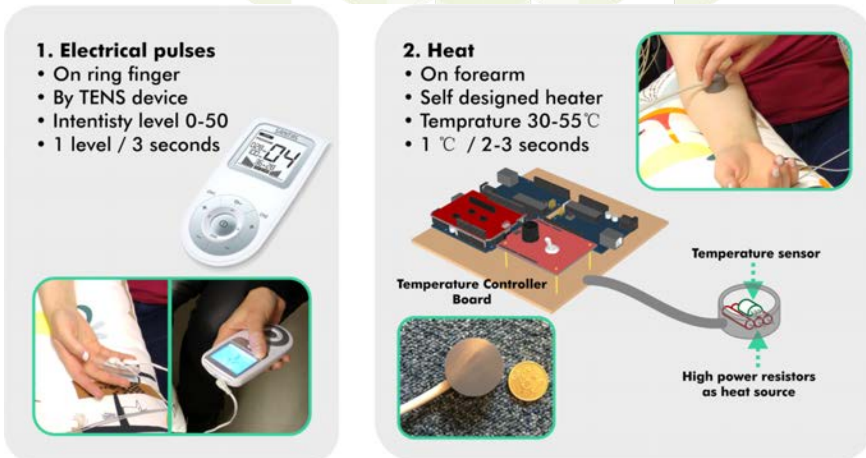
Pain Stimulation



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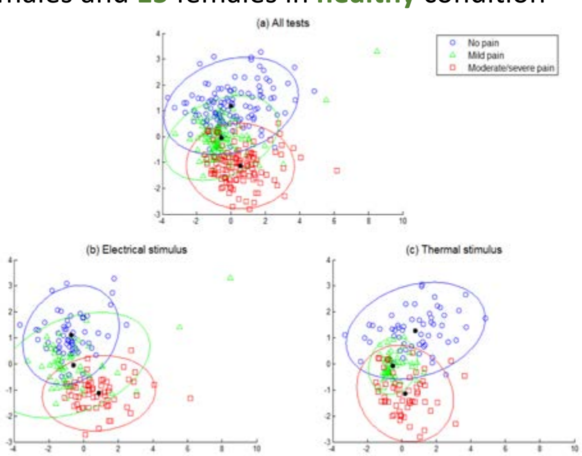
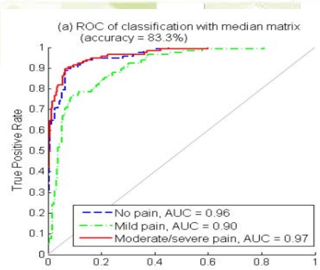
Results

15 males and 15 females in healthy condition



Machine learning using ANN classifiers



Mingzhe Jiang, Riitta Mieronkoski, **Amir M. Rahmani**, Nora Hagelberg, Sanna Salanterä, and Pasi Liljeberg, "Ultra-Short-Term Analysis of Heart Rate Variability for Real-time Acute Pain Monitoring with Wearable Electronics," IEEE International Conference on Bioinformatics and Biomedicine (BIBM'17), 2017.

Mingzhe Jiang, Riitta Mieronkoski, Elise Syrjälä, Arman Anzanpour, Virpi Terävä, **Amir M. Rahmani**, Sanna Salanterä, Riku Aantaa, and Pasi Liljeberg, "Acute pain intensity monitoring with the classification of multiple physiological parameters", Springer Journal of Clinical Monitoring and Computing (JCMC), 2018 (under second revision).

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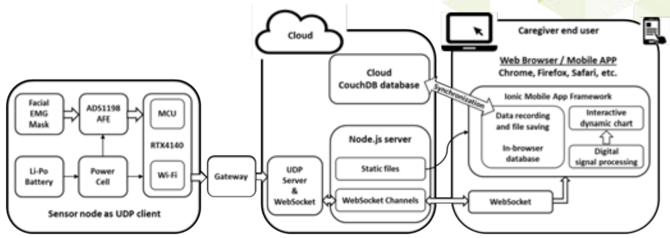
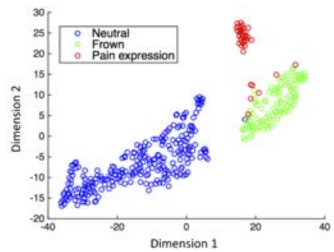
Wearable Mask





Geng Yang, Mingzhe Jiang, Wei Ouyang, Guangchao Ji, **Amir M. Rahmani**, Pasi Liljeberg, and Hannu Tenhunen, "IoT-based Remote Pain Monitoring System: from Device to Cloud Platform," IEEE Journal of Biomedical and Health Informatics (IEEE-JBHI), 2017.

A mask-like device for detection, assessment, treatment, and consciousness monitoring, registered in U.S. Patent and Trademark Office, **US Provisional Patent**, EFS ID: 22905354.

Transparent polydimethylsiloxane (PDMS) material

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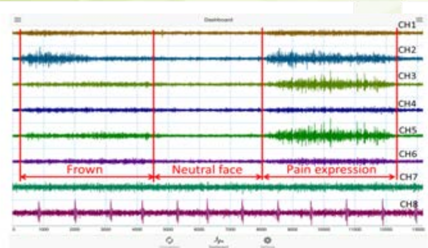
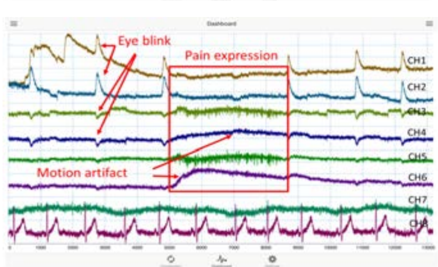
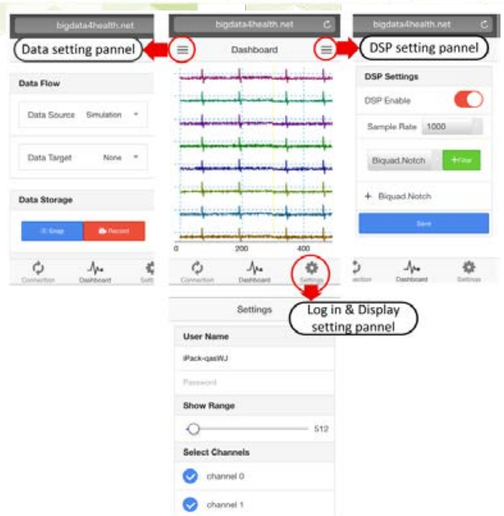
Dashboard and Cloud Connectivity







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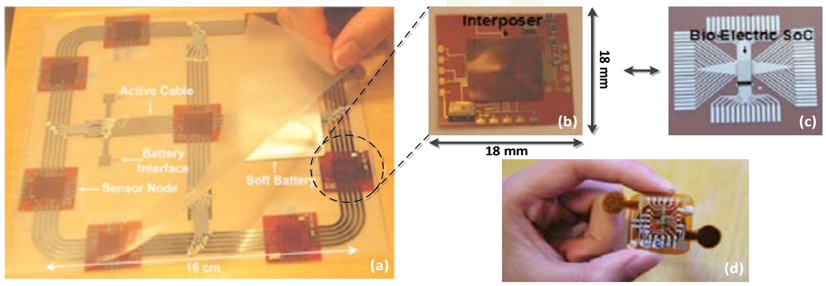
Bio-patch Sensors



(a) Prototype of Polyimide (PI) based Bio-Patch wired sensor network, (b) Sensor node assembly, (c) Sensor node before assembly (Flip chip bonding with Anisotropic conductive adhesive (ACA)), (d) a single bio-patch sensor

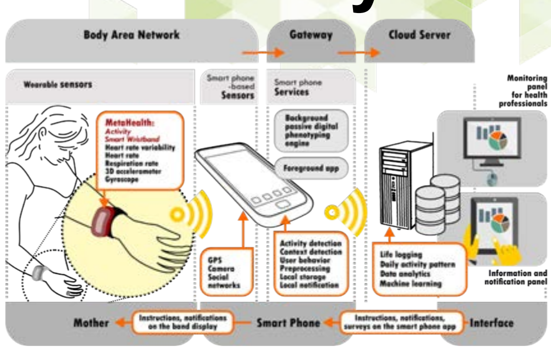
Ongoing Trials

- Parallel trials in **Finland** (TYKS) and the **US** (UCIMC)
- Elective **surgical patients**
  - requiring **recovery room care** treatment after surgery
  - requiring **general anesthesia**

Outline

- Internet-of-Things (IoT)
  - IoT in Healthcare
  - HiCH Architecture
- **Healthcare IoT Case Studies**
  - 1. IoT-based Early Warning Score (EWS) in Everyday Settings
  - 2. Smart Pain Assessment Tool Based on IoT
  - 3. Family Centered Monitoring in Maternity Care
- Future Research Directions

❸ Family Centered Monitoring in Maternity Care

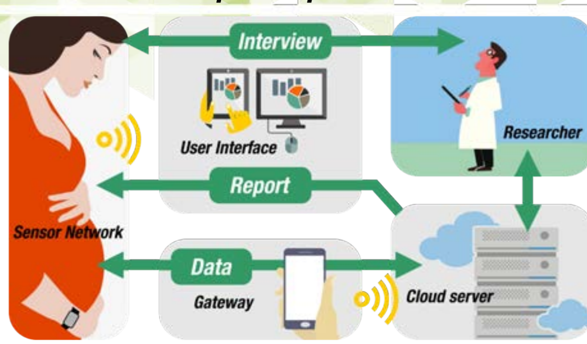


Research Questions

1. **Observational study** using wearables to understand the possibility of **long-term** monitoring of **maternal activity, medical parameters** and **sleep**
2. How **feasible** smart tracker is for monitoring **maternal activity** and **sleep** during pregnancy?
3. Which parameters pregnant women would **like** to measure concerning their pregnancy and the fetus?

Physical activity and heart rate
during pregnancy and one month postpartum

- **20** pregnant during **7 months** of pregnancy to **one month** after delivery.
- We monitored
  - **Heart rate**
  - **Physical activity level**
  - **Sleep level**



- Women are **interviewed** on their views and needs related to monitoring.
- More parameters: BMI, Blood pressure, Special conditions

The Participants

- The population includes women with
  - high BMI (> 40)
  - gestational diabetes
  - smokers
  - low education and socioeconomic status
  - women expecting alone
  - women with unplanned pregnancies



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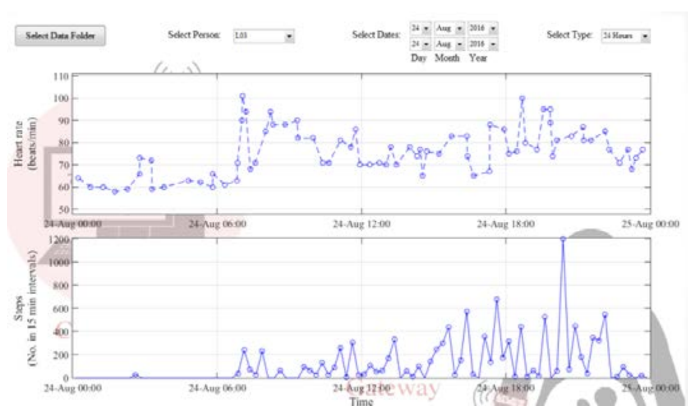
Daily Analysis - 24 Hours

- Every **minute** of about **4000 days** of data:
  - Heart rate, resting heart rate
  - Sleep quantity and quality
  - Step counts
  - Number of stairs climbed
  - Activity intensity
  - Calories burned



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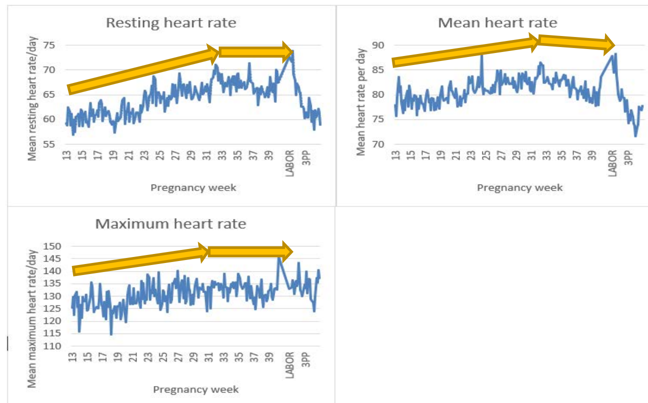
The Results

Mean resting heart rate
- **16.7%** increase from **13** weeks of gestation until **32** gestational weeks
- remained in that level until delivery

Mean steps/hour/day:
- 2nd trimester:481
- 3rd trimester: 356
- Postpartum: 263



J. Saarikko, E. Ekholm, H. Niela-Vilén, L. Hamari, I. Azimi, P. Liljeberg, A.-M. Rahmani, E. Löyttyniemi, and A. Axelin, "**Physical activity and heart rate during pregnancy and one month postpartum: the seven-month observational study with wearable sensors**", Elsevier International Journal of Nursing Studies, 2018 (Elsevier-IJNS, under review).

The Results II

- The **recommended duration for physical activity** in healthy pregnant women is
  - **150 minutes** of moderate-intensity activity per week or
  - **75 minutes** of vigorous-intensity activity per week (ACOG, 2015)

- Objectively measured
  - **46** (range 0-288) minutes per week at moderate-to-vigorous intensity

Conclusions

Physical activity of primiparous pregnant women was **low**, the **intensity levels** were **insufficient**.
Self-reported data was **in line** with the objective data.

The Feasibility Study

- The outcomes of interest were the **wear time of the device** and **participant's experiences** of the smart wristband.
- Participants used the smart wristband **an average of 163 days during the 7-month** study period.
- **Similar** at 2nd and 3rd trimester but **decreased** at **postpartum**
  - **17.9** hours (range 4.3–23.6) per day 2nd trimester

Conclusion

A smart wristband is **a feasible tool** to monitor health data during pregnancy

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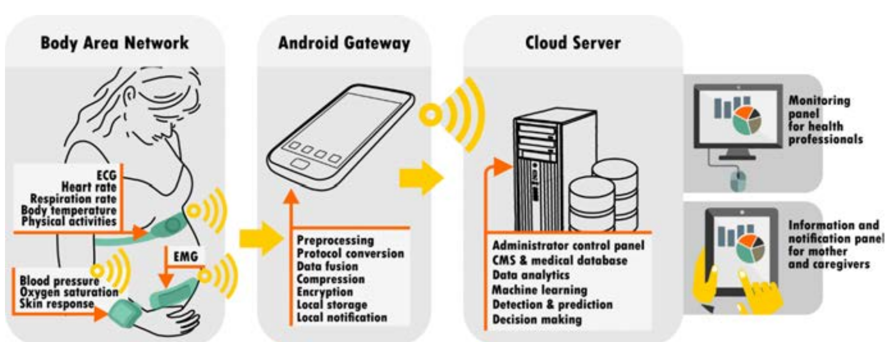
Preterm Birth Prevention in Everyday Settings
(Ongoing)

- We aim to create a **ubiquitous monitoring**, **early detection**, and **prevention** system for mothers at the risk of preterm birth to be used in their **everyday settings**



PREVENT: Preterm Birth Prevention in Everyday Settings, Consortium Leader and PI, ICT 2023 programme funded by **Academy of Finland**, UTU Dept. of Future Technologies and Dept. of Nursing Science Consortium. **01/2018-12/2019** (≈600,000 USD)

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Outline

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- **Future Research Directions**

UNITE: Smart, Connected, and Coordinated Maternal Care for Underserved Communities

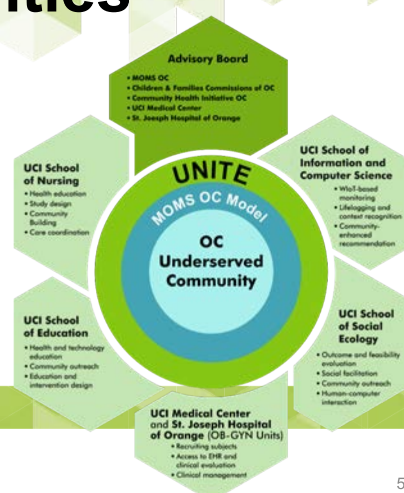
NSF Smart and Connected Communities call

$2.1M for 4 years

Objective is to develop IoT-based **Personalized Monitoring and Recommendation System**

To support and enhance **self-management** of mothers in the **MOMS OC** community

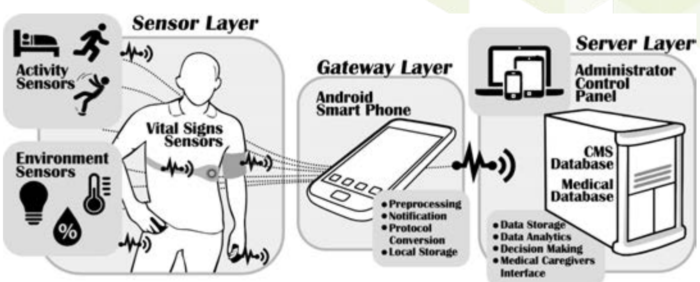
To expand the **community outreach**



Summary

- We proposed HiCH for healthcare IoT.
  - A hierarchical computing architecture for partitioning and execution of machine learning data analytics
  - A closed-loop management technique enabled by autonomic system adjustment with respect to patient's condition.
- We introduced an IoT-based EWS system using the concept of self-awareness to offer:
  - A personalized and self-organized decision making system for patients engaged in various activities in different environments.
  - A self-awareness enabled method to improve the system's energy efficiency and its confidence in its computed results.
- We demonstrated the benefits of our solutions in a proof of concept full system implementation.

Key Take-away 1: Internet of Cognitive Things (IoCT) in Healthcare

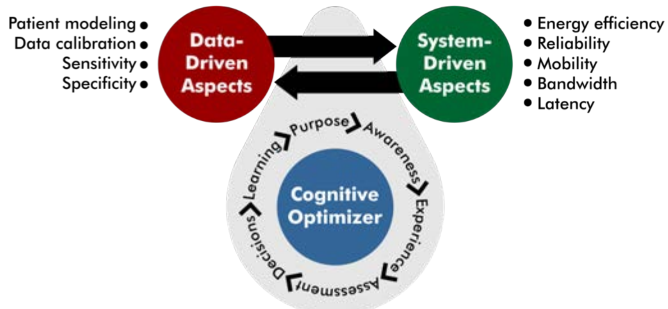


- **IoT** and **wearable** technologies to:
  - **Continuously track patients**
  - **Personalization**
  - **Predict health status**
  - **Self-management**
  - **Prevention & Smart intervention**

- The IoT paradigm **holds significant promises** in **healthcare** domain.
  - ↑ **access to care**
  - ↓ **healthcare costs**

Key Take-away 2: Quality of Experience Management

- IoT-based health monitoring applications need to provide a high level of quality attributes.



- Need a cognitive architecture to support intelligent IoT

Major Collaborators

Turun yliopisto University of Turku

UCI University of California, Irvine

KTH ROYAL INSTITUTE OF TECHNOLOGY

TU WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna | Austria

Fudan University Department of Information Technology