DESIGN, AUTOMATION & TEST IN EUROPE
27 – 31 March, 2017 · STCC · Lausanne · Switzerland
The European Event for Electronic System Design & Test

Self-Awareness in Remote Health Monitoring Systems using Wearable Electronics

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Introduction

- **Chronic diseases** which are the leading causes of death and disability worldwide are **increasing**:
  - They are directly related to the age.
  - They population of aged people is increasing.
- Early recognition of sudden deterioration in chronic patients is possible with continuous monitoring of vital signs.
- Many signs of deterioration exist as early as 24 hours prior.

Early Warning Score (EWS)

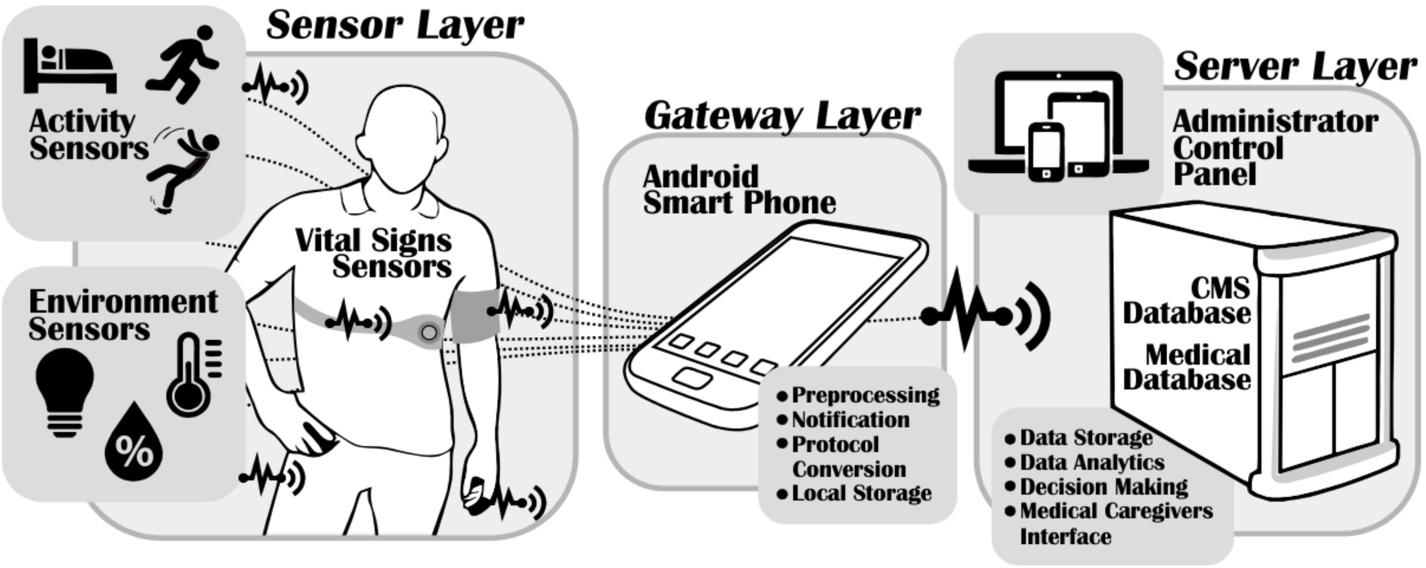
- **Early Warning Score** is a scoring method for assessment of patient condition and detection of emergency situations in hospital.
- It is based on recording the patient’s vital signs.

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

- Final score is the sum of all individual scores and the treatment order of the patient will be changed based on the score results.

Internet of Things

- **Internet of Things (IoT)** and wearable technologies provide a competent and structured approach to automatically:
  - Enable health monitoring systems
  - Continuously track patients
  - Predict health status
- We presented in our earlier research an implementation of **IoT-based EWS** using a set of medical sensors attached to patient's body to record and process physiological parameters:



Challenges

Remote patient monitoring and Early Warning Score is not possible in out-of-hospital scenarios mostly because:

- Several parameters like **patient’s activities** and **environment** affects the interpretation of vital signs outside the hospital.

- Mobile and wearable sensors face disparate constraints such as:
  - Energy source
  - Reliability
  - Computational power

Solution

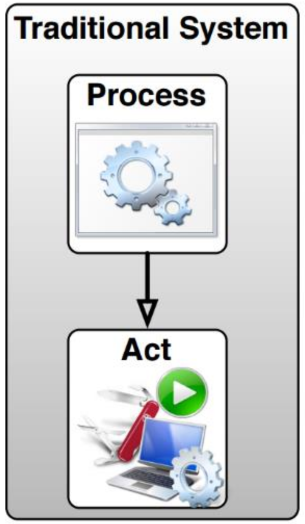
- We propose an IoT-based system architecture to extend EWS to remote monitoring of patients out of the hospital.

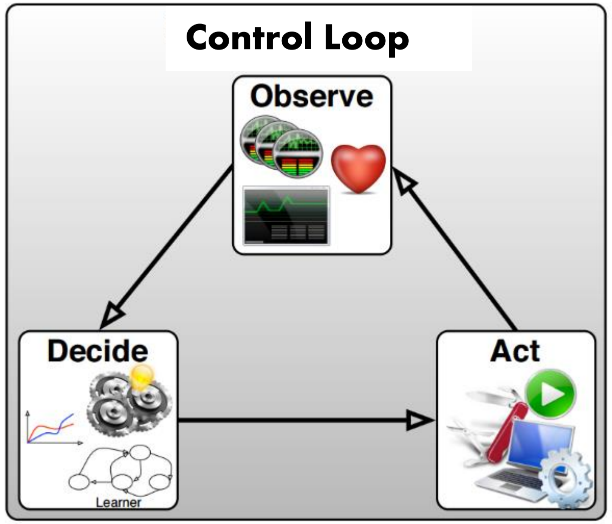
- **Self-awareness** principles can be leveraged to reinforce the EWS system to tackle the challenges.

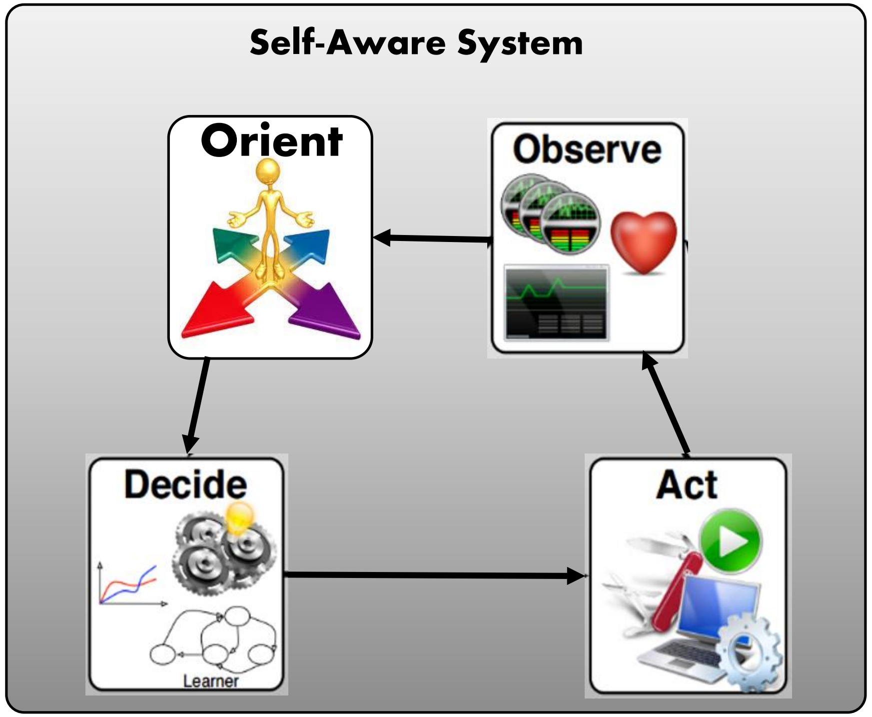
- The notion of self- and context-awareness can enhance and personalize the score calculation process to implement intelligent reasoning and decision making.

Self-awareness

- **Self-awareness** is the ability to be aware of its own state as well as the state of its surrounding environment to adapt to new situations.
- **Self-awareness** provides the necessary tools to obtain many dynamically changing characteristics of interest, such as reliability, adjustability and optimality.
- **Observe-Orient-Decide-Act (OODA) loop:**
  - **Observe:** Sensor network data collection and pre-processing
  - **Orient:** Situation awareness and self-awareness
  - **Decide:** Assess the situation and decide
  - **Act:** Reconfiguration

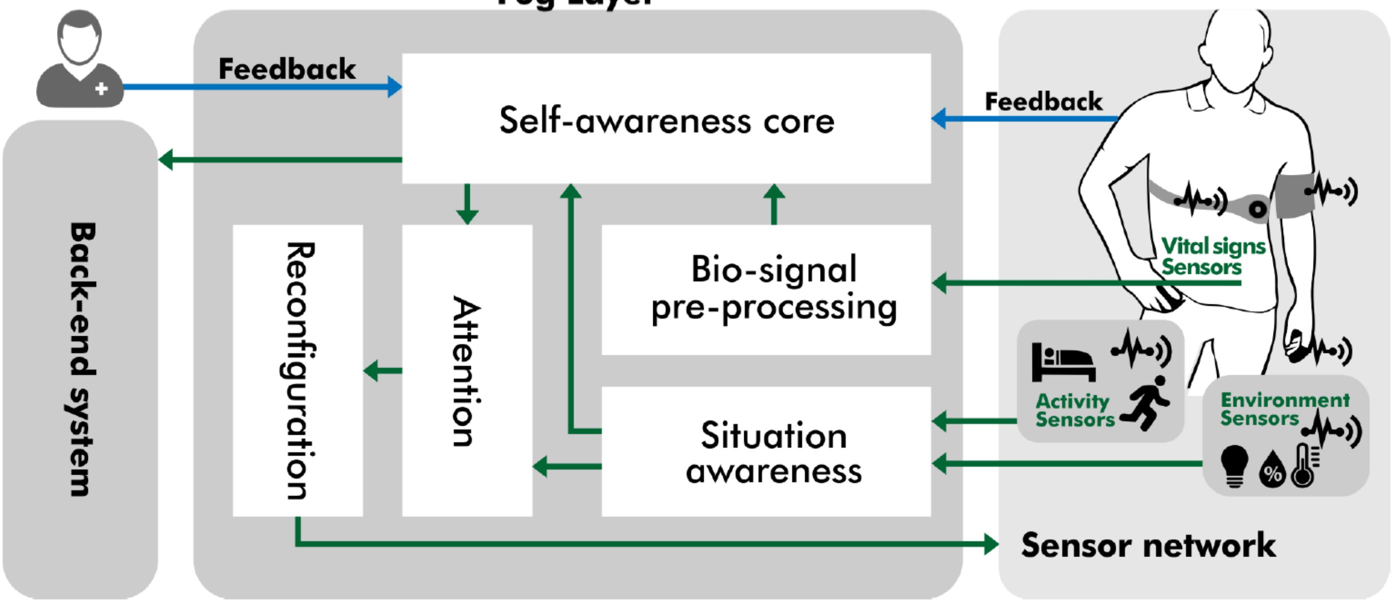






Proposed System Architecture

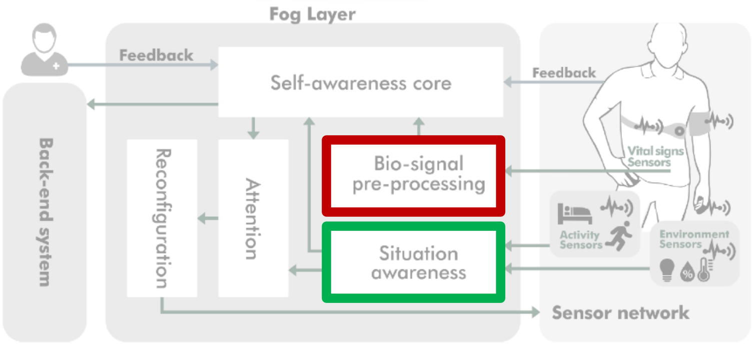
- The proposed system architecture addresses the challenges from both the user and system perspectives with **self-awareness** concept in an **IoT-enabled** health monitoring system.
- 5 different components of the fog layer are operating in a closed-loop system to
  - Intelligently correct EWS values
  - Configure sensor network

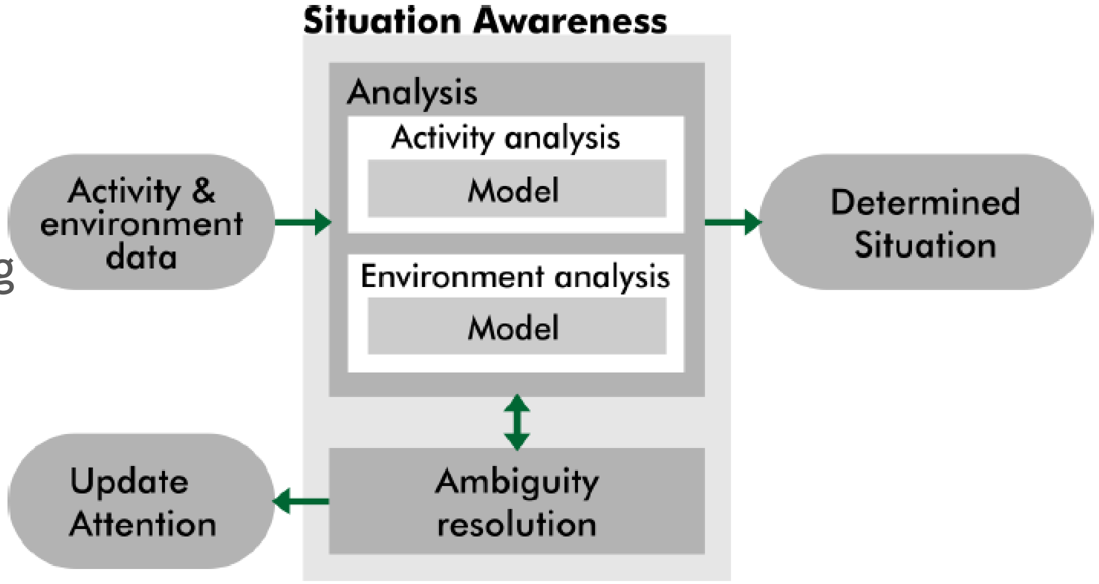


System Components (1)

- **Bio-signal Pre-processing:**
  - Receives raw signals from sensor nodes and converts the data to a format usable by higher level processing units.

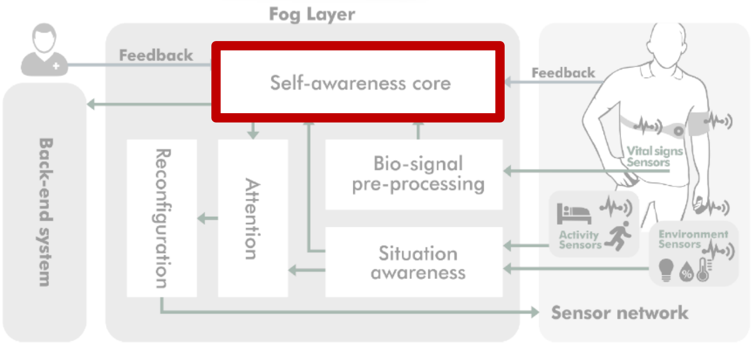
- **Situation Awareness:**
  - Receives activity and environmental data from the sensor network and provides:
  - **Analysis:** determines patient situation using activity and environment data.
  - **Ambiguity resolution:** updates system’s setup according to the determined situations by requesting new information sources in case of ambiguity.

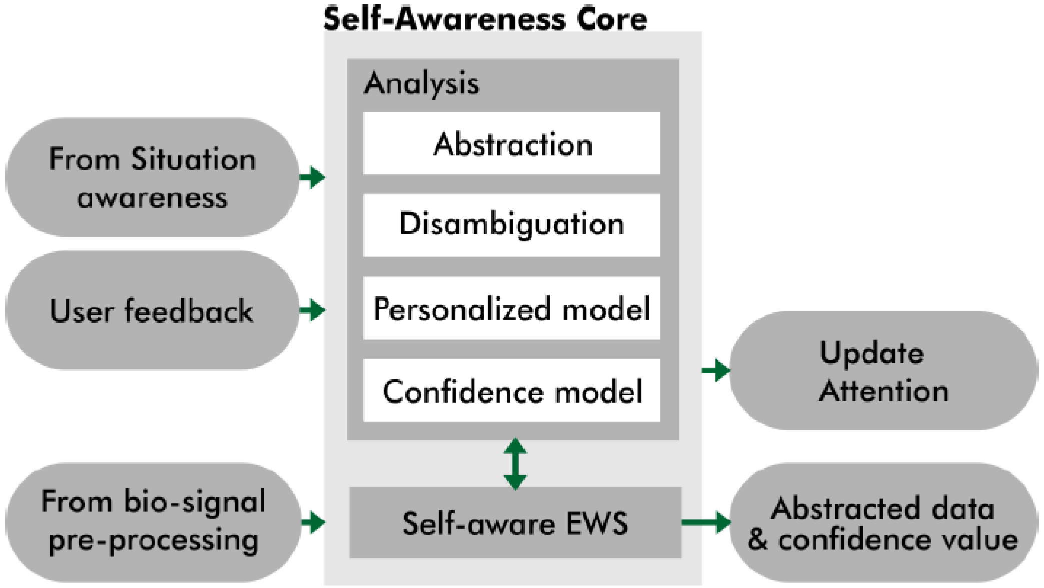




System Components (2)

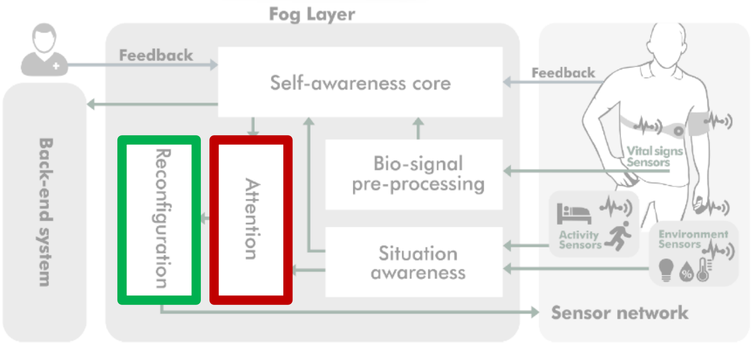
- **Self-awareness Core:** is the main analytical component of the system which
  - Tunes the system configuration and refines abstracted patient data.
  - Receives vital signs and situation values and provides an enhanced context-aware and personalized EWS.
  - Provides confidence assessment of the input data and correction methods to eliminate data consistencies.
  - **Analysis module:** provides meaningful information for the models and the back-end users with abstraction and disambiguation.
  - **Self-aware EWS module:** adjusts the traditional EWS value using the Analysis unit's results and the determined situation and a pre-defined rule-based algorithm.

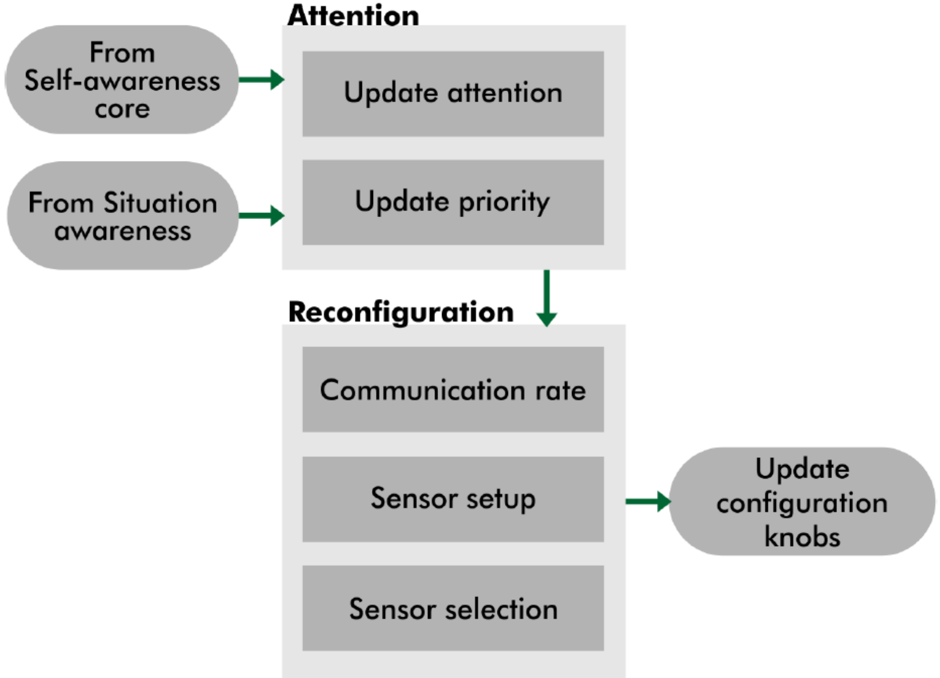




System Components (3)

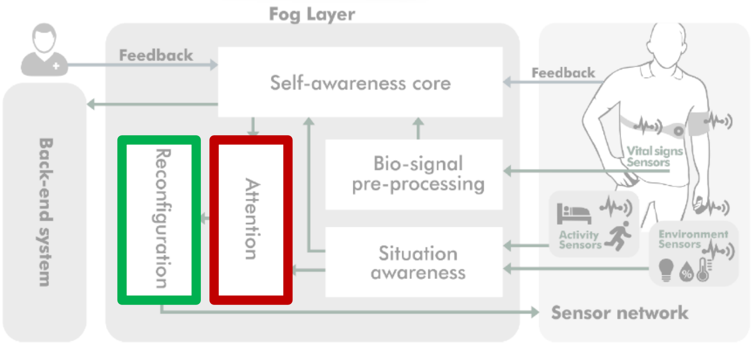
- **Attention:** is the planning component which adaptively tunes monitoring knobs to enhance system characteristics, confidence, and quality of the sensory data.
  - **Attention module**: determines which parameters should be monitored and how often.
  - **Priority module**: determines which requirements are of more importance and which ones can be omitted in the case of insufficient available resources.
- **Reconfiguration:** receives the priority values from the Attention unit and maps them to the corresponding state of the sensor network.





System Components (4)

- **Priorities:**
  - Activity mode
  - Health condition
  - Situation

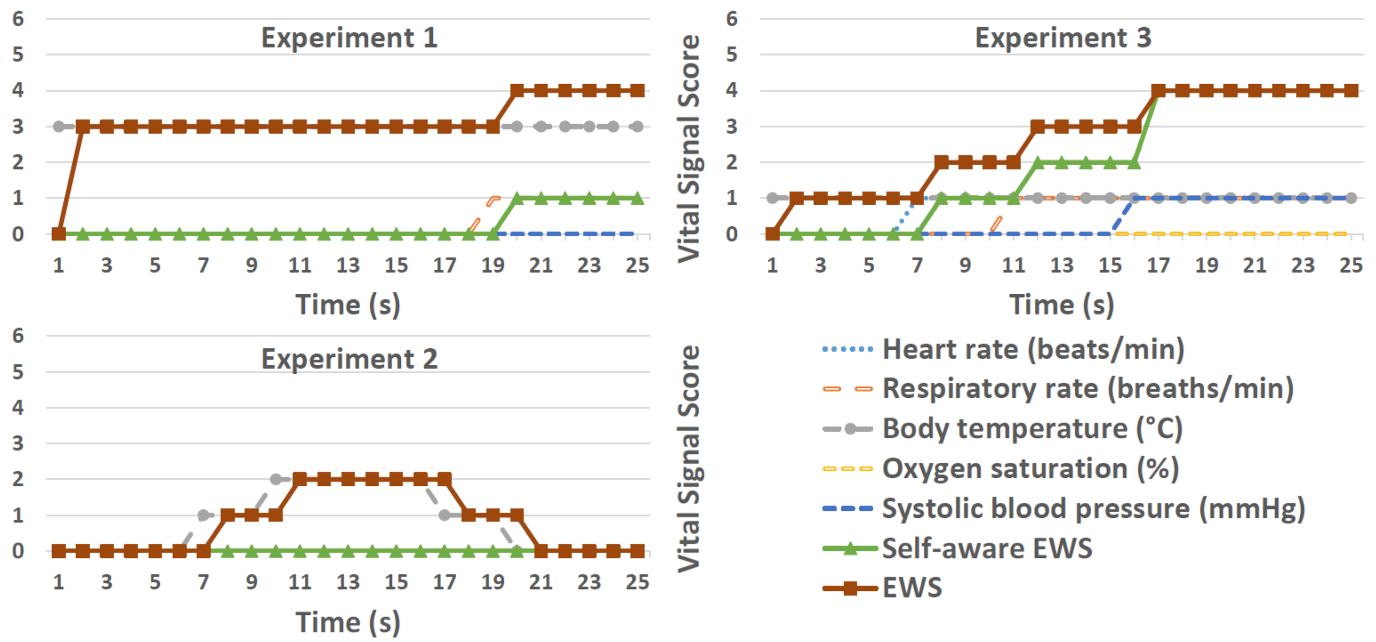


Demonstration and Evaluation

- We present 3 demonstrations:
  1. **Adjusting EWS based on data reliability**
  2. **Adjusting EWS based on the situation**
  3. **Optimizing energy efficiency using Attention**

Demonstration and Evaluation (1)

1. **Adjusting EWS based on data reliability (confidence):**
   - **Experiment i**
     (a value in a plausible range):
     a faulty value is injected in data. Due to the absence of a validation system, the conventional EWS results score 3, while the Self-aware EWS correctly shows the score 0.
   - **Experiment ii**
     (a value with plausible rates of change):
     with a sudden drop in normal body temperature, the system identifies the body temperature as unconfident and Self-aware EWS shows score 0.

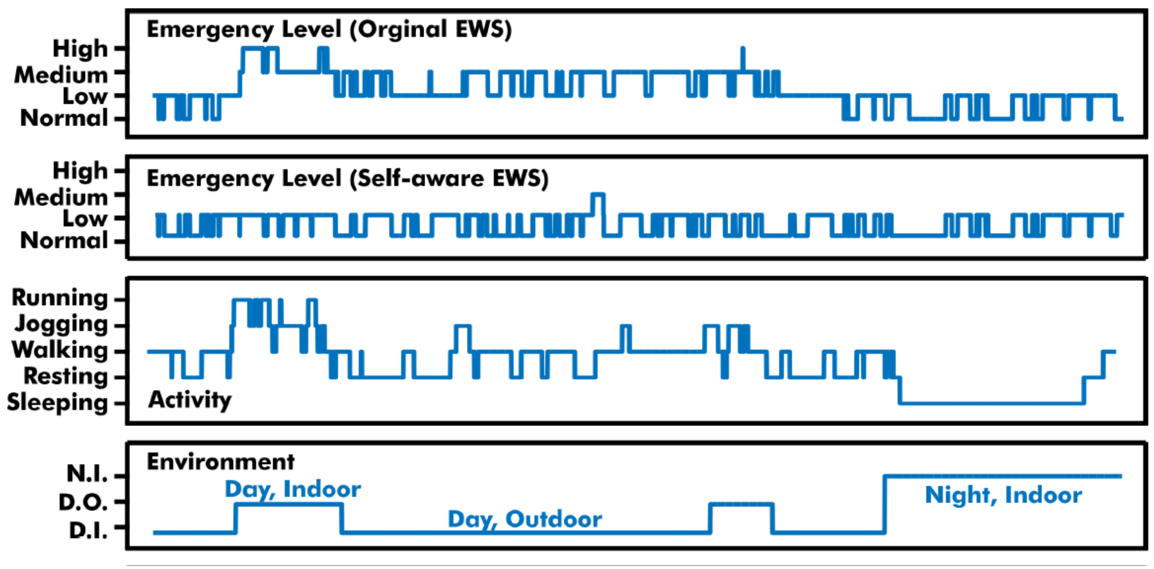


   - **Experiment iii**
     (correspondence with other vital signals):
     The body temperature is set to a value which is equivalent to score 1. Only when more than 50% of other signals have a non-zero status, the temperature is tagged as confident, and the Self-aware EWS becomes equal to the conventional EWS.

Demonstration and Evaluation (2)

2. Adjusting EWS based on the situation:

- We improve the standard EWS method by considering the fact that the patient is not in a standard clinical environment.
- Patient activities are measured with a 3D accelerometer sensor.
- Environment is detected in 4 states: Indoor/Outdoor/Day/Night
- Activities, environment and vital signs of a 35 years old healthy male subject are recorded for 8 hours.
- The first chart shows the original EWS which issues several false alarms while the subject is running and jogging.

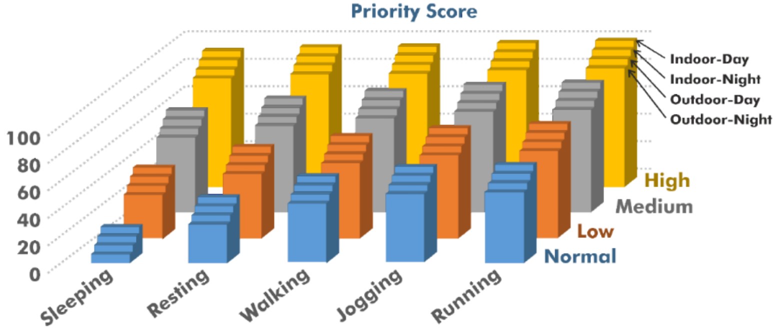


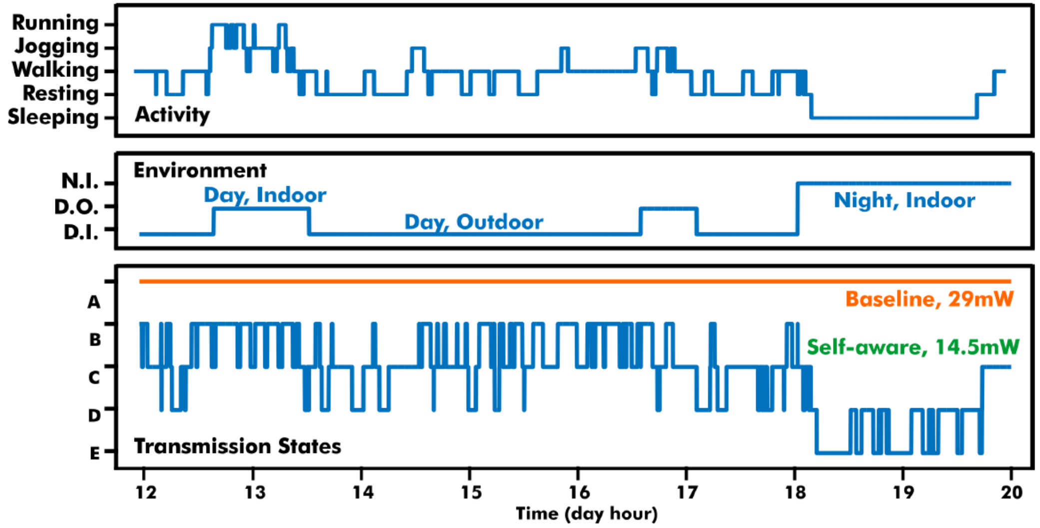
- The second chart shows the self-aware EWS considering the state of the activity and environment which can be seen from the third and fourth charts.
- The results show that self-aware EWS correctly reports the normal and low emergency levels in 99% of the monitoring samples.

Demonstration and Evaluation (3)

- **Optimizing energy efficiency using Attention:**
  - The energy consumption optimization of an HM-11 Bluetooth low energy module is demonstrated.
  - Based on the power consumption of Bluetooth module, 5 states for transmission are defined.
  - A lookup table is designed based on the priorities in attention module.
  - After looking up a proper state, a new configuration state is sent back to the MCUs in the sensor network to update the transmission rate and activity mode of the transmission module.
  - The last row in the chart shows that the overall power consumption of the transmission is reduced by 50% to 14.5mW compared to a baseline non self-aware system which consumes 29mW.

State	Respiration Rate Activity	Blood Pressure	Heart Rate, SpO2, and Body Temp.	Transmission Power Consumption
A	Continuous	Every hour in day Disabled in night	Every sec.	29 mW
B	2 min continuous 8 min OFF	Every hour in day Disabled in night	Every sec.	26.8 mW
C	2 min continuous 3 min OFF	Every 3 hours in day Disabled in night	Every min.	12.5 mW
D	2 min continuous 8 min OFF	Every 3 hours in day Disabled in night	Every min.	7 mW
E	2 min continuous 18 min OFF	Disabled	Every min.	4.3 mW





Emergency Level:	Score:0 Normal				Score:1-3 Low				Score:4-6 Medium				Score>6 High			
	Indoor		Outdoor		Indoor		Outdoor		Indoor		Outdoor		Indoor		Outdoor	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Sleeping	E	E	E	E	C	D	D	D	B	C	C	C	A	A	B	B
Resting	D	D	D	D	C	C	C	C	B	B	B	B	A	A	B	B
Walking	C	C	C	C	B	C	C	C	B	B	B	B	A	A	A	B
Jogging	C	C	C	C	B	B	B	C	B	B	B	B	A	A	A	B
Running	C	C	C	C	B	B	B	B	B	B	B	B	A	A	A	[illegible]

Conclusions

- In this research, 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 solution in a proof of concept full system implementation which reveals an improved level of data dependability and system energy efficiency compared to conventional open-loop systems.


? Questions ?