AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Multimodal Measurement Systems for Health and Behavior Analysis in Living Environment

Piotr Augustyniak

AGH - University of Science and Technology
Department of Biocybernetics and Biomedical Engineering

Scientific work supported by the AGH University of Science and Technology grant no. 16.16.120.773

Agenda

1. Introduction
2. Basic assumptions – who spies whom and why
3. Sensors and Sensor Networks
    1. Sensor Types and Characteristics
    2. Intelligent sensors
    3. Imperceptible Sensors
    4. Sensor Network
    5. Sensor Information Safety
4. Digital Behavioral Record
    1. Physical Representation of Behavior
    2. Symbolic Representation of Behavior
5. Identifying and Predicting Human Actions
6. Perspectives and challenges

Introduction

Changing World:

passive – accept and adapt, wait and see ....

active – predict and innovate (!)

Introduction

Changing World:

passive – accept and adapt, wait and see ....

active – predict and innovate (!)

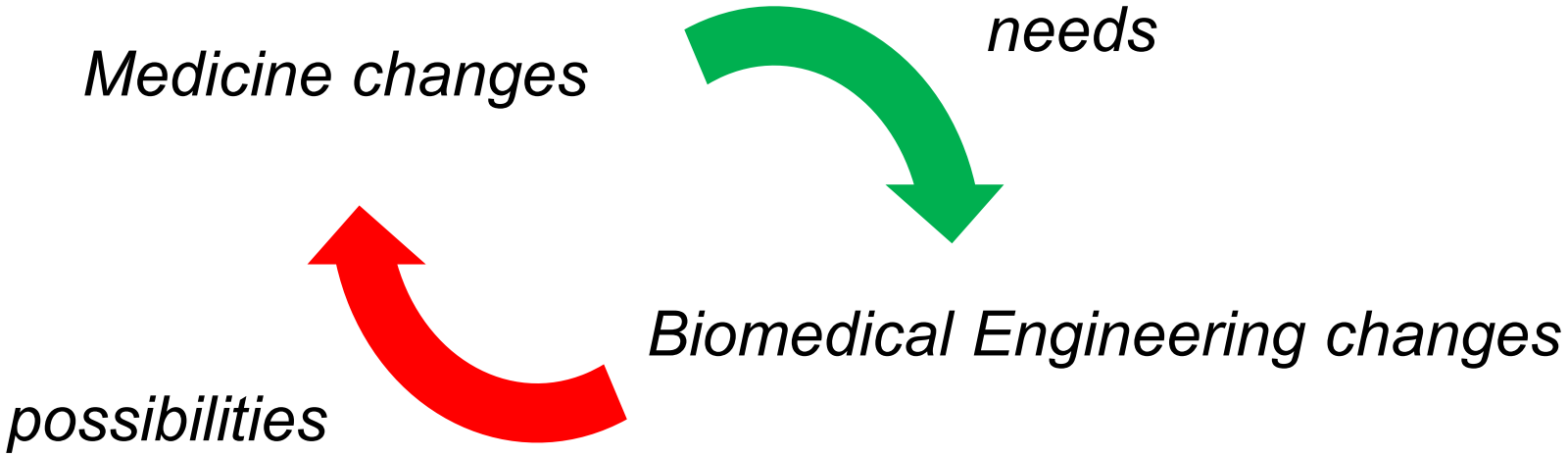
Peter Drucker (1909-2005, father of Management Thinking)

The best way to predict your future is to create it

The entrepreneur always searches for change, responds to it, and exploits it as an opportunity

change management

Introduction



Introduction

challenges:

Medicine changes

Biomedical Engineering changes

we are here

new areas:

Introduction

EMBS conference in Berlin:

new definition

approach to standardization :

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN Workshop on guidelines for introducing tele-medical and pervasive monitoring technologies balancing privacy protection against the need for oversight and care

11 July 2019 – 09:00-15:30 CET

Introduction

Changes in medicine (1): prevention matters

→ *large populations (not yet patients) are concerned (pervasive medicine)*

Changes in medicine (2): continuous care matters

→ *the people (not yet ill) are under health surveillance for longer time (seamless care)*

Basic assumptions – who spies whom and why

Fragile information:

- human health status (employment or insurance fraud),
- human activity (burglary),
- human habits (offending advert).

A.I.

Basic assumptions – who spies whom and why

Invigilation comes with communication, entertainment, comfort, convenience and home automation devices such as:

- Smartphones, PDAs, and iPods (voice, image vibration and position),
- Computers,
- DVD players,
- Cable/on demand TV, TiVo and WebTV decoders
- Gaming consoles (Xbox etc.)
- Uninterruptible power supplies

U.S. Department of Justice Office of Justice Programs National Institute of Justice Special OCT. 07 REPORT Investigative Uses of Technology: Devices, Tools, and Techniques
http://www.ojp.usdoj.gov/nij

Basic assumptions – who spies whom and why

Invigilation comes with communication, entertainment, comfort, convenience and home automation devices such as:

- Smartphones, PDAs, and iPods (voice, image vibration and position),
- Computers, WiFi – enabled entertainment hubs (e.g. Chromecast)
- DVD players, cameras, camcorders,
- Cable/on demand TV, TiVo and WebTV decoders
- Gaming consoles (Xbox etc.)
- Uninterruptible power supplies, etc.

U.S. Department of Justice Office of Justice Programs National Institute of Justice Special OCT. 07 REPORT Investigative Uses of Technology: Devices, Tools, and Techniques
http://www.ojp.usdoj.gov/nij

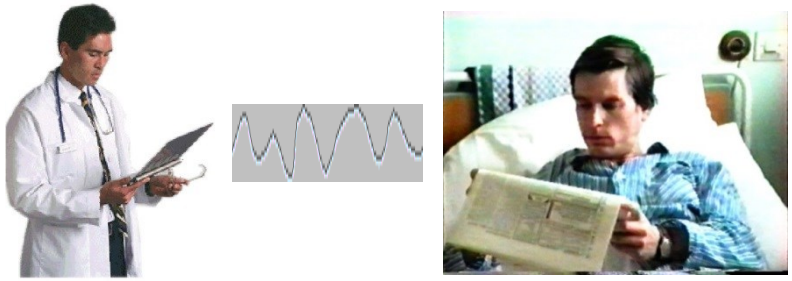
privacy

ambient inlelligence

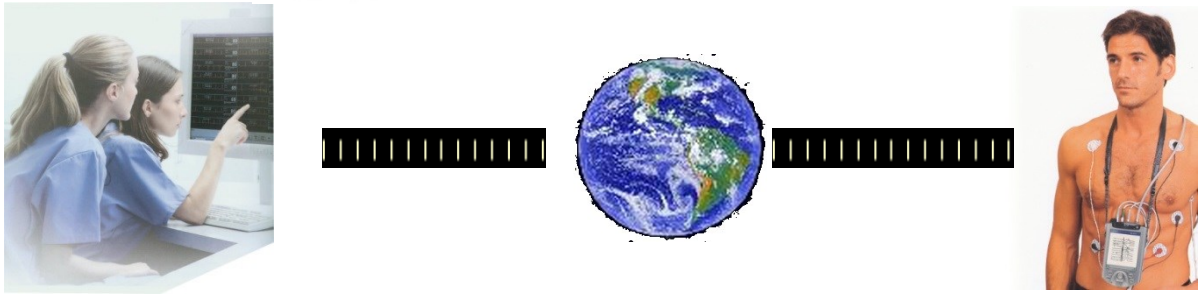
Basic assumptions – who spies whom and why

Medical diagnosis is based on relations, measurement and information exchange

direct relation:



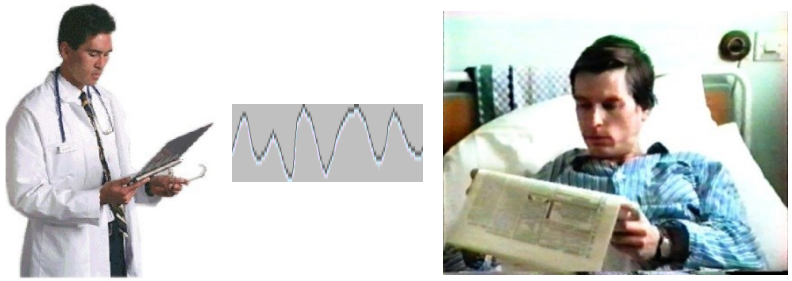
indirect relation:



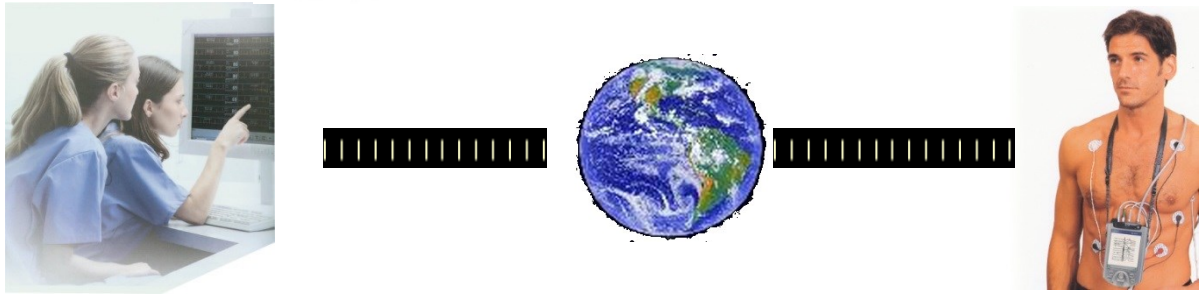
Basic assumptions – who spies whom and why

Medical diagnosis is based on relations, measurement and information exchange

direct relation:



indirect relation:



? *privacy*

ubiquitous healthcare

Basic assumptions – who spies whom and why

Medical information types:

- raw signals and images,
- annotated signals and images,
- diagnostic results,
- disease classification data,
- demographic data,
- equipment commands and status data,
- ...

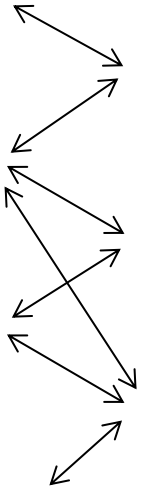
Medical information recipients:

- clinicians,
- healthcare providers,
- social security institutions,
- patient,
- patient relatives,
- medical scientists,
- ...

Basic assumptions – who spies whom and why

Medical information types:

- raw signals and images,
- annotated signals and images,
- diagnostic results,
- disease classification data,
- demographic data,
- equipment commands and status data,
- ...



Medical information recipients:

- clinicians,
- healthcare providers,
- social security institutions,
- patient,
- patient relatives,
- medical scientists,
- ...

The key is proper management and protection of privacy related information:

- authentication of sources and recipients,
- protection against unauthorized access or modification,
- protection of continuous accessibility and quality.

Basic assumptions - who spies whom and why

?

WHY IS MEDICAL DEVICE CYBER SECURITY TESTING IMPORTANT?

There are multiple regulatory, ethical and business reasons to ensure that all digital healthcare and medical devices are thoroughly tested and secure, including:

- Compliance with regulatory requirements such as the In Vitro Diagnostic Medical Device Regulation (IVDR), the In Vitro Diagnostic Medical Device Directive (IVDD), the Medical Device Regulation (MDR), Medical Device Directive (MDD), and the Active Implantable Medical Device Directive (AIMDD) in the EU; as well as the regional requirements of the US FDA, China FDA and the Japan Ministry of Health and Welfare
- Unauthorised access to medical devices could result in death or severe injury, so manufacturers and medical device procurement teams must ensure the technology is secure
- Privacy is extremely important for patient confidentiality – a breach would undermine that privacy

unknown brand

medical device

Basic assumptions – who spies whom and why

Rationales behind the Ambient Assisted Living (AAL):

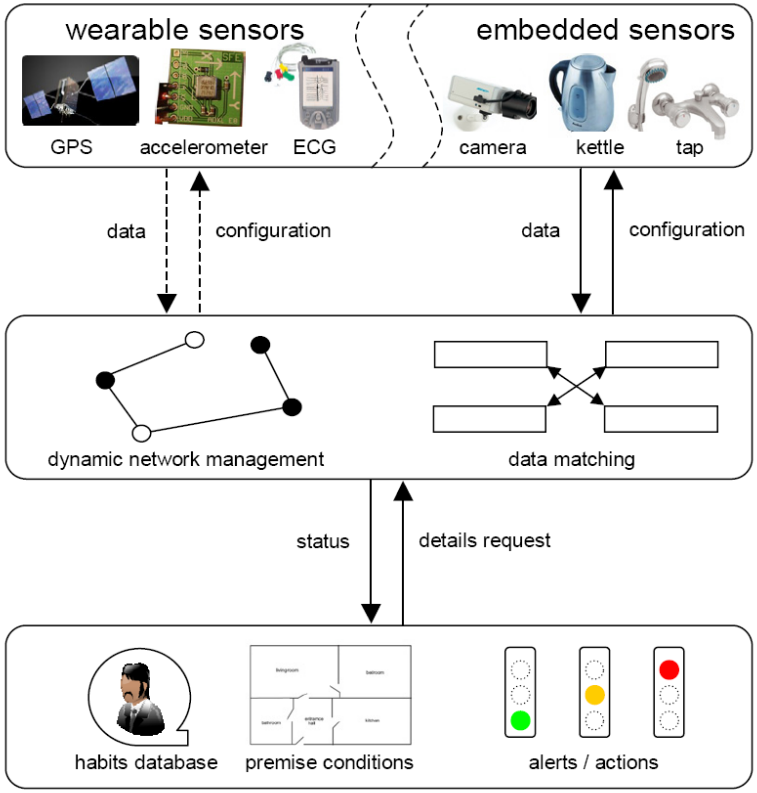
– Majority of accidents take place in households and concern senior adults so substantial social and economic costs can be saved due to prevention.

– Each appliance in the household is engineered with specific assumptions about user abilities and technical performance; both factors decrease with time narrowing the safety margin.

– Functional impairment immediately follows subtle pathologic changes at the cell level; performance drop precedes other measurable markers of several diseases.

Basic assumptions – who spies whom and why

Layered design of the Ambient Assisted Living System (2012)



Augustyniak, P., Layered Design of an Assisted Living System for Disabled, Pietka, E; Kawa, J. Information Technologies in Biomedicine, ITIB 2012, pp. 498-509.

Basic assumptions – who spies whom and why

Layered design of the Ambient Assisted Living System (2012)

- Sensor layer, physical wearable and infrastructure (IoT) sensors, the data collection and management system, secure data transport.
- Behavioral record layer with preprocessing, storage and retrieval sub-systems,
- Inference and prediction machine, interface to alerting and intelligent home (environment) subsystems.

Augustyniak, P., Layered Design of an Assisted Living System for Disabled, Pietka, E; Kawa, J. Information Technologies in Biomedicine, ITIB 2012, pp. 498-509.

Sensors and Sensor Networks

1. **Sensor Types and Characteristics**
2. Intelligent sensors
3. Imperceptible Sensors
4. Sensor Network
5. Sensor Information Safety

Sensor Types and Characteristics

In medical / technical measurements the accuracy and stability are two key parameters of sensors.
In case of behavioral studies the **unobtrusive** or even **imperceptible** operation is the most welcome feature.

For continuous measurements in human, the **unobtrusiveness** corresponds to the lack of influence of the act of measurement to the process of interest what is a fundamental rule of metrology.

Sensor Types and Characteristics

Direct measurement:

The captured value (voltage) is directly passed to the wire-connected recorder.

- *huge data volume*
- *immediate recording*

Indirect measurement:

The captured value is transduced to analog or digital (electrical) form and passed to the receiver via cable, radio waves, optical link voice etc.

- *data processing,*
- *data coding*
- *sensor programmability*
- *internet of things*
- *internet od artificial intelligence*

Sensor Types and Characteristics

Unimodal multilead measurement

- a single phenomenon is recorded in various aspects and yields simultaneous time series of samples called dimensions,
- all signals are of the same nature, expressed in the same measurement units and are considered as equally important,
- all measurement channels are identical as much as technically possible,

Examples: ECG, EEG, ...

Multimodal measurement

- a single phenomemon or several coinciding phenomena are simultaneously measured with different physical principles (modalities),
- each signal has his own nature, is expressed in respective measurement units and prioritized,
- each measurement channel is idividual with own transducers, digitizers and processing methods.

Examples: PSG, KTG, ...

Sensor Types and Characteristics

Infrastructure (embedded) sensors,

- fixed in a specific location to monitor changes in a given range of the space (environment),
- part of subject's premises: home, office, vehicle,
- not restricted from power requirements,
- typically wired networking.

Wearable sensors,

- fixed to the monitored individual and capturing changes in his or her body or in the environment he or she interacts with,
- implanted or worn by the subject, as a device or as a part of clothing,
- restricted from power / data requirements,
- typically wireless networking

Sensors and Sensor Networks

Sensor Types and Characteristics

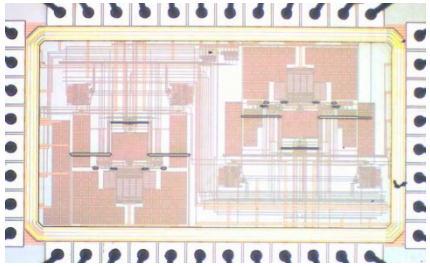
Infrastructure (embedded) sensors,

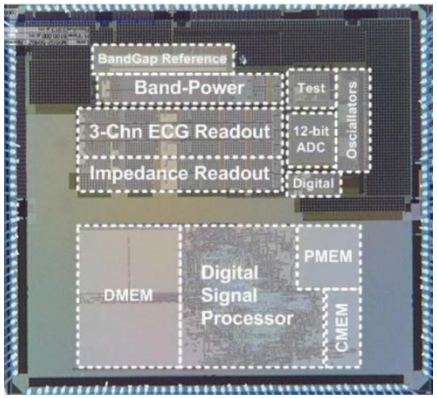
Wearable sensors,

Sensor Types and Characteristics

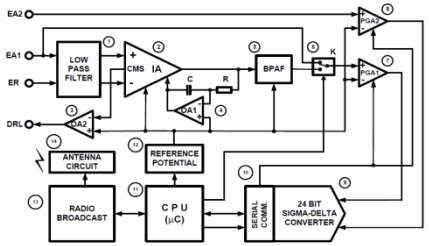
Recent trends in electrophysiological sensor development

(1) reducing the power consumption and size of the sensor with maintaining limited programmability,





(2) increasing the on-site processing power and agility without the significant growth of size and energy consumption



Sensors and Sensor Networks

1. Sensor Types and Characteristics
2. **Intelligent sensors**
3. Imperceptible Sensors
4. Sensor Network
5. Sensor Information Safety

Intelligent sensors

dynamic configuration of network architecture:
subject/sensor, present/absent

multimodal data acquisition:
audio, video, ECG, accelerations, GPS, EEG, oculomotoric…

simultaneous support of different subject-specific detection rules

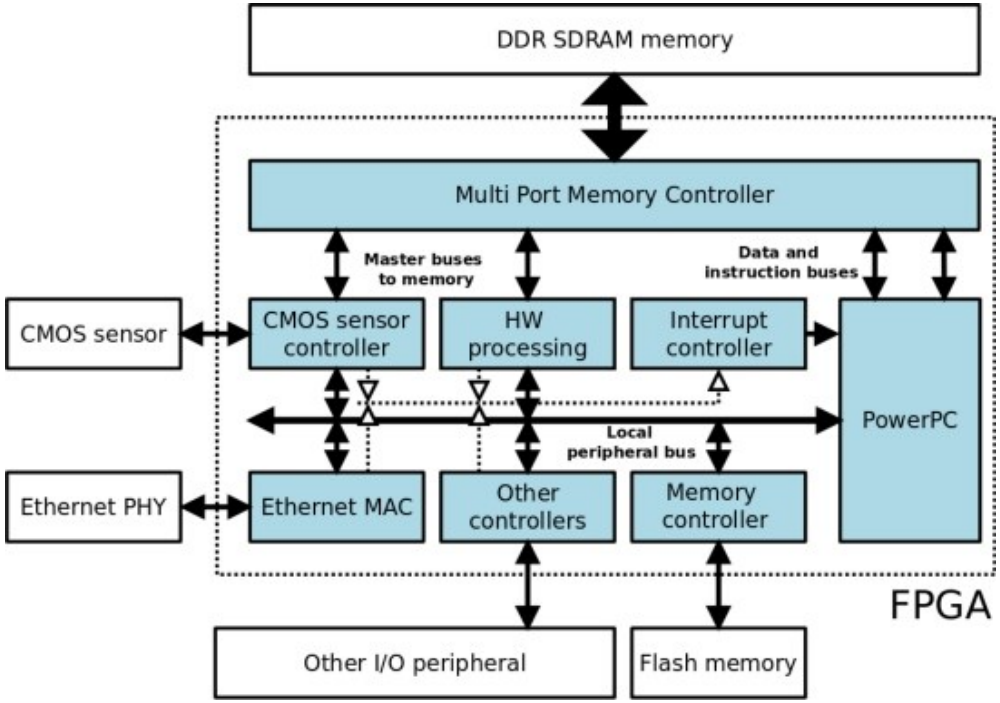
- programmable sensors and communication rules,
- adaptive detection of subject's action and
- intelligent classification of events as control- or health status-related

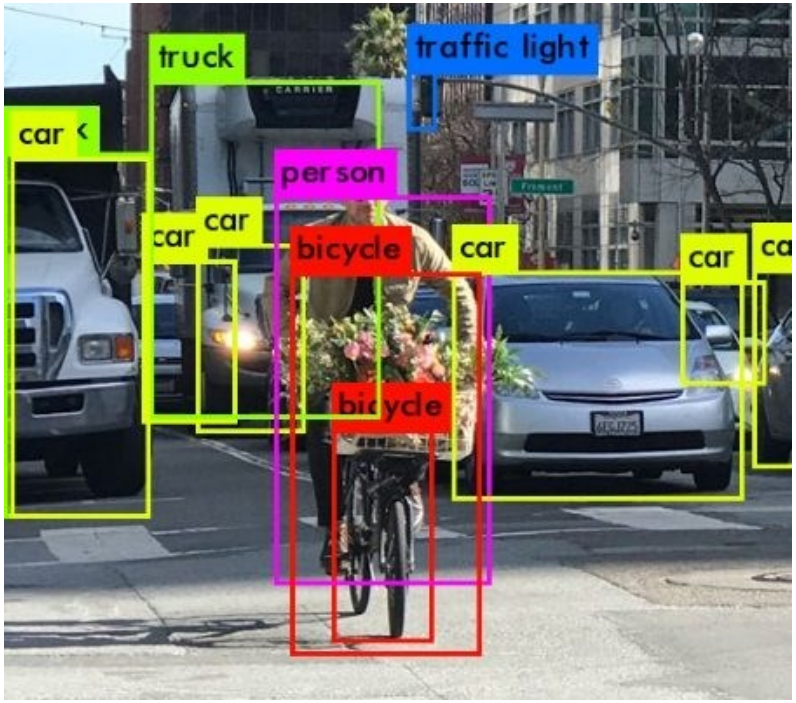
Intelligent sensors

Intelligent camera
Regular camera with on-board real-time image processing and object identification (*helps privacy preservation*)

Intelligent sensors

Intelligent camera



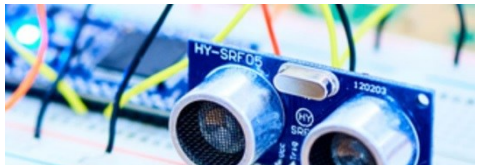


Sensors and Sensor Networks

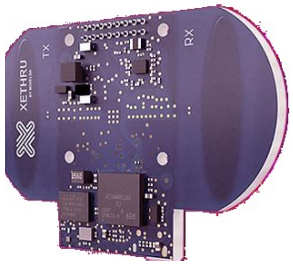
Intelligent sensors

Sound

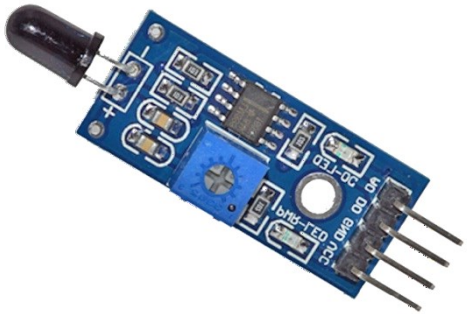
Ultrasound



Wideband radar



Infrared

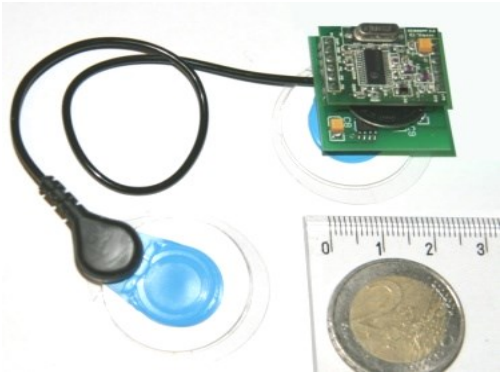


Radiation

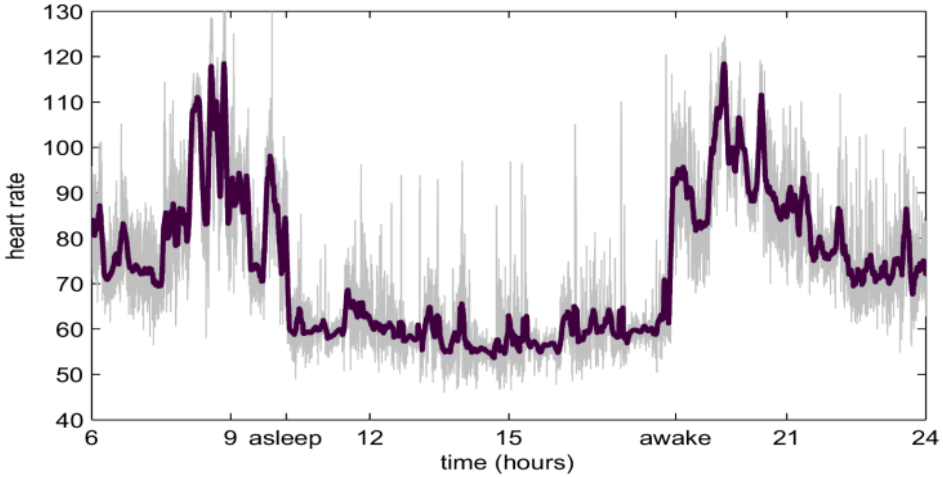
Sensors and Sensor Networks

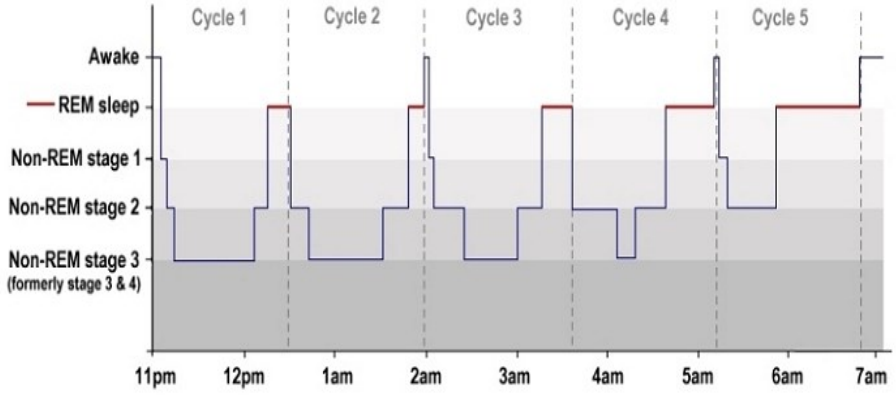
Augustyniak, P., Wearable wireless heart rate monitor for continuous long-term variability studies. J. of Electrocardiology 44(2), 195-200

Intelligent sensors



Smoleń 2010





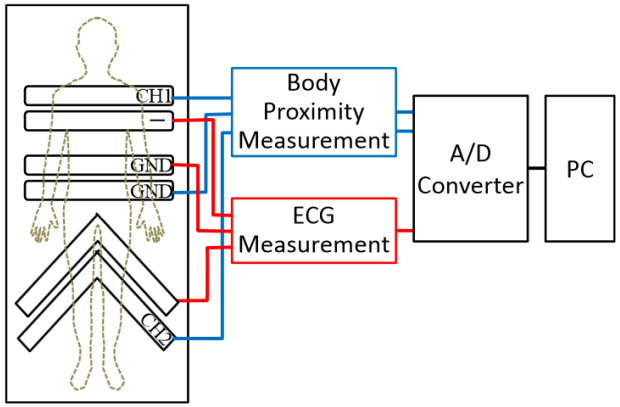
Sensors and Sensor Networks

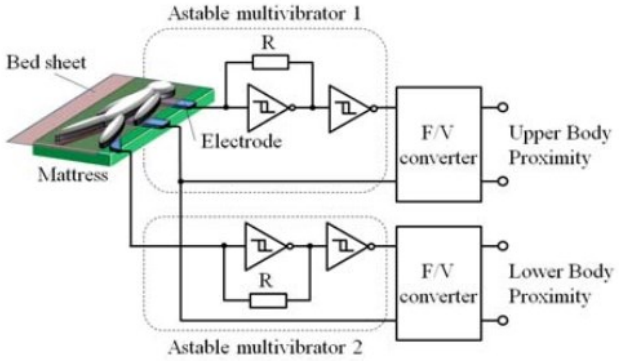
1. Sensor Types and Characteristics
2. Intelligent sensors
3. **Imperceptible Sensors**
4. Sensor Network
5. Sensor Information Safety

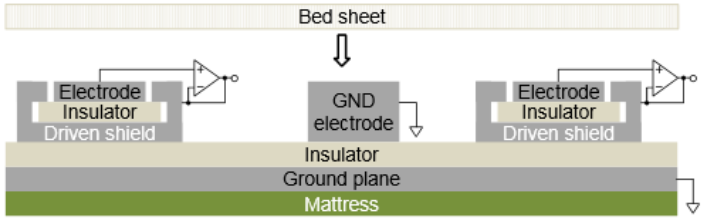
Sensors and Sensor Networks

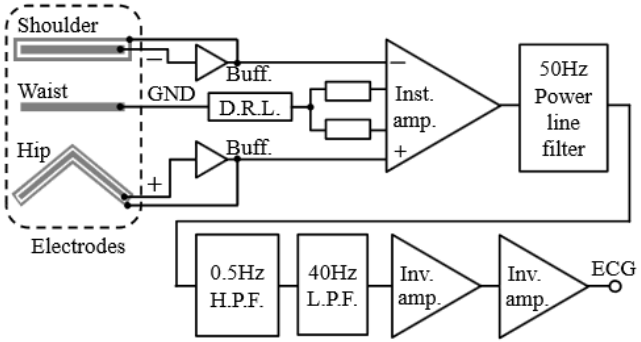
Imperceptible Sensors

piezoelectric mattress – an electrocardiograph in the bed



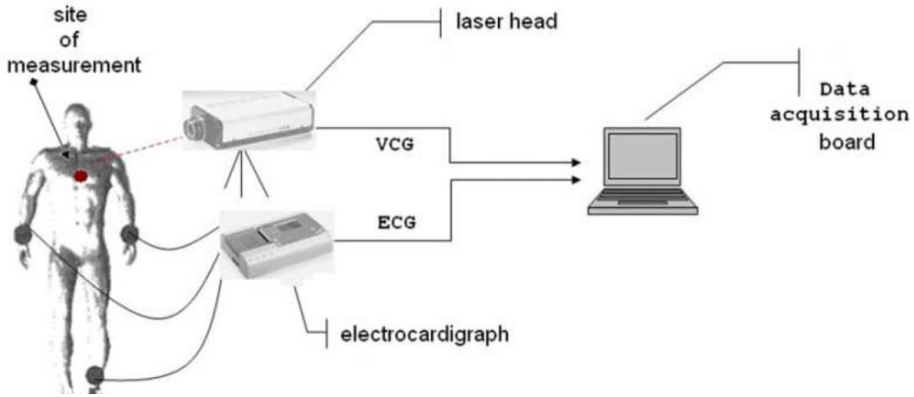




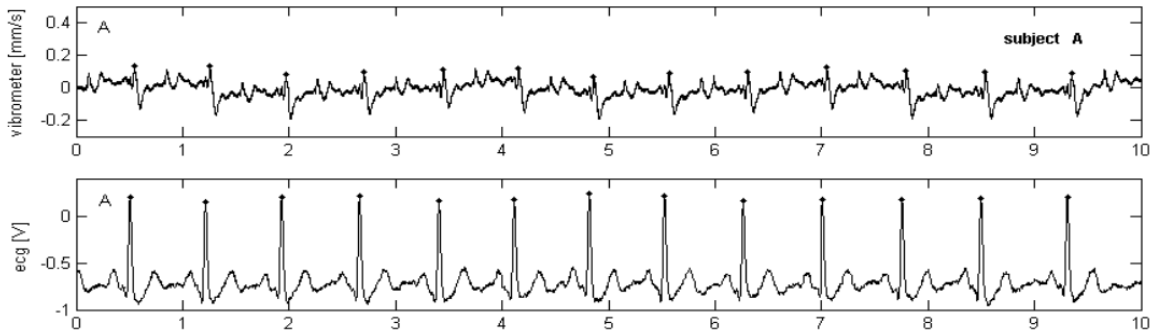


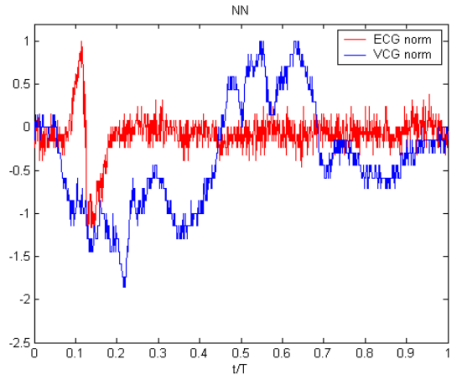
Imperceptible Sensors

laser vibrocardiography



the use of Dopplera effect to analysis of carotid artery displacement related to bood pulse

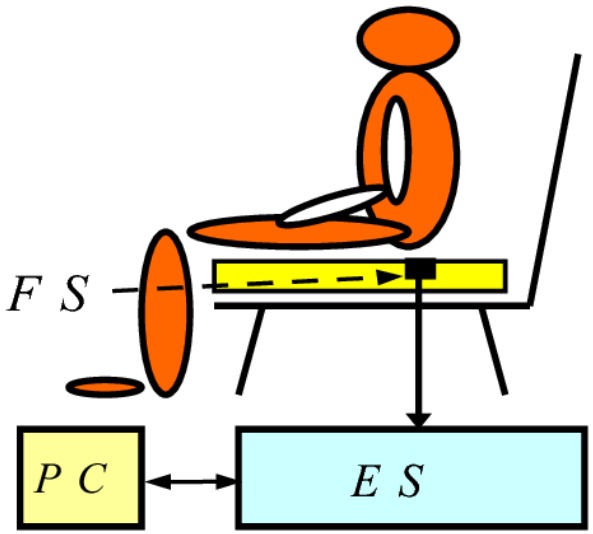


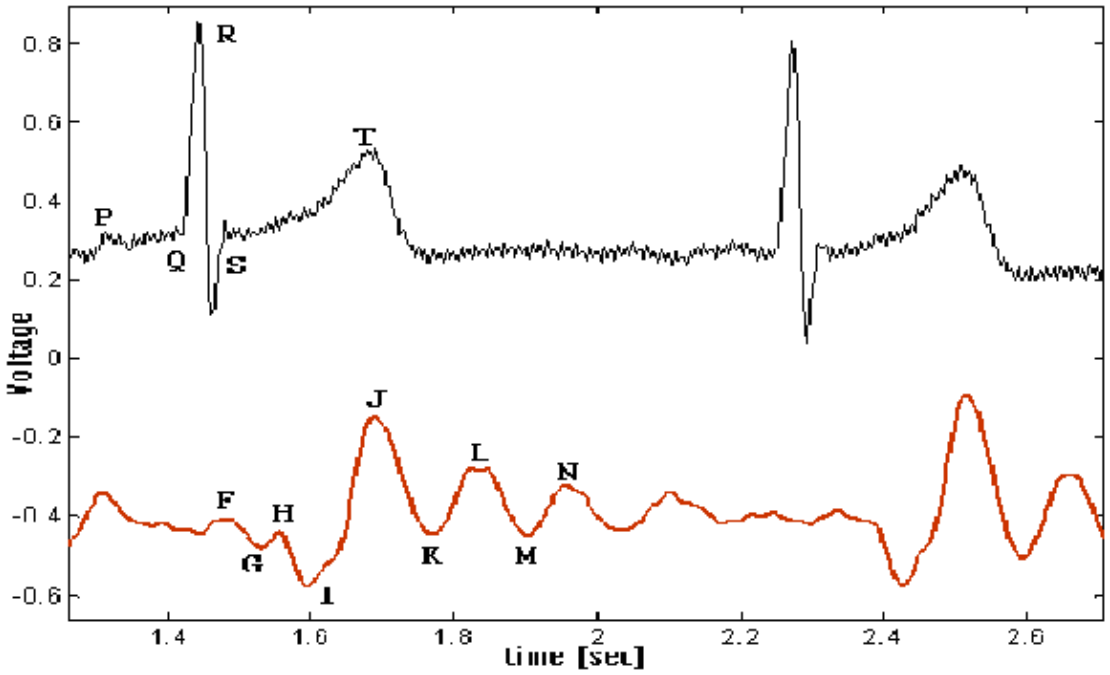


Sensors and Sensor Networks

Imperceptible Sensors

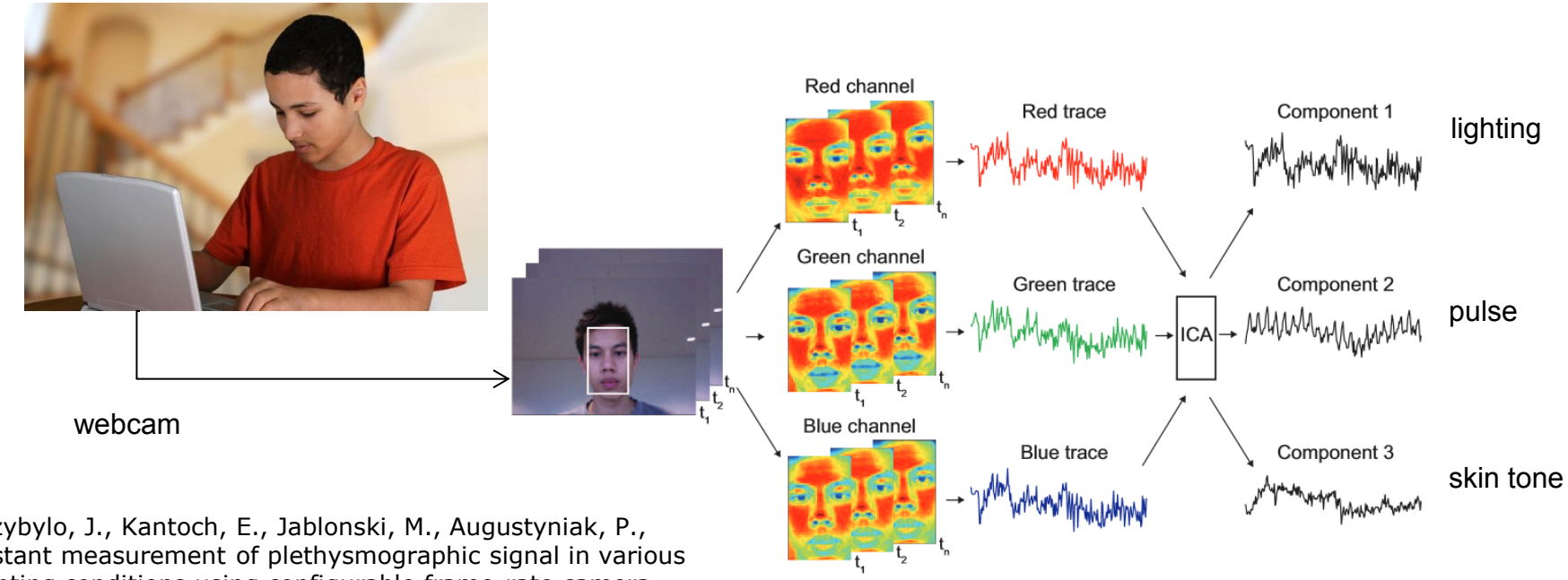
balisto (seismo-) cardiography





Imperceptible Sensors

videoplethysmography – pulse rate from a regular camera

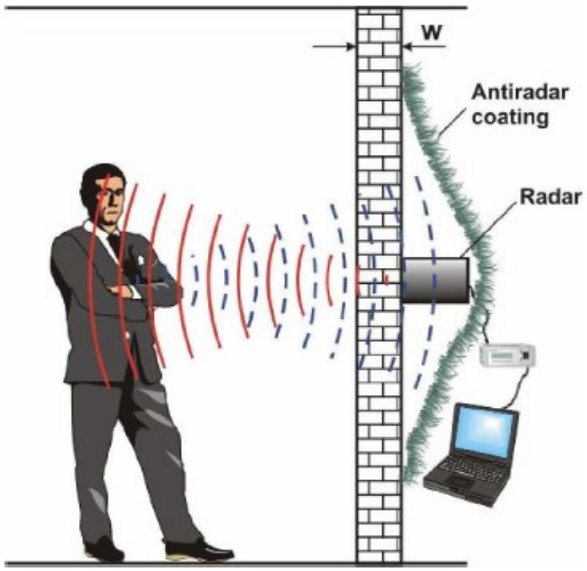


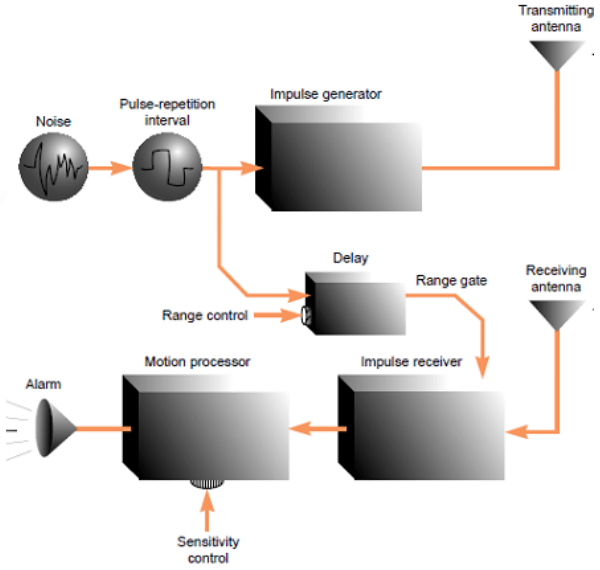
Przybylo, J., Kantoch, E., Jablonski, M., Augustyniak, P., Distant measurement of plethysmographic signal in various lighting conditions using configurable frame-rate camera. Metrology and Measurement Systems, 23(4) pp. 579-592

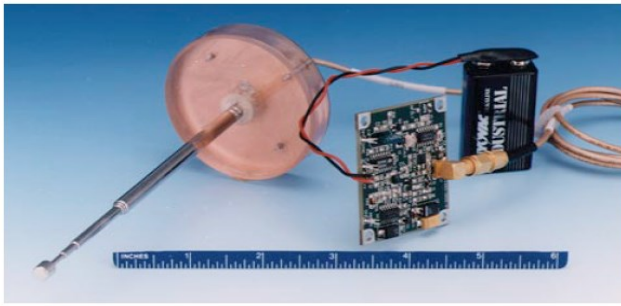
Sensors and Sensor Networks

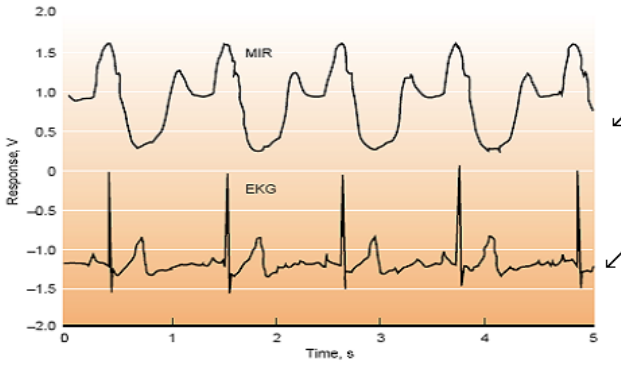
Imperceptible Sensors

microwave impulse radar – pulse rate from behind a wall







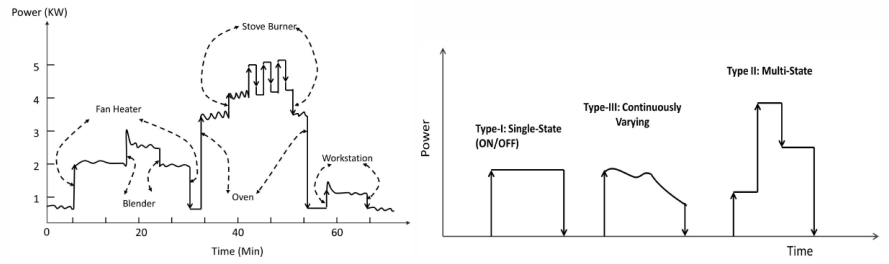


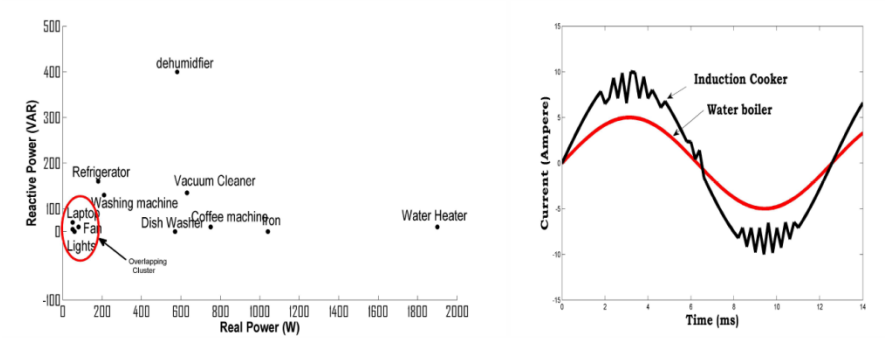
Sensors and Sensor Networks

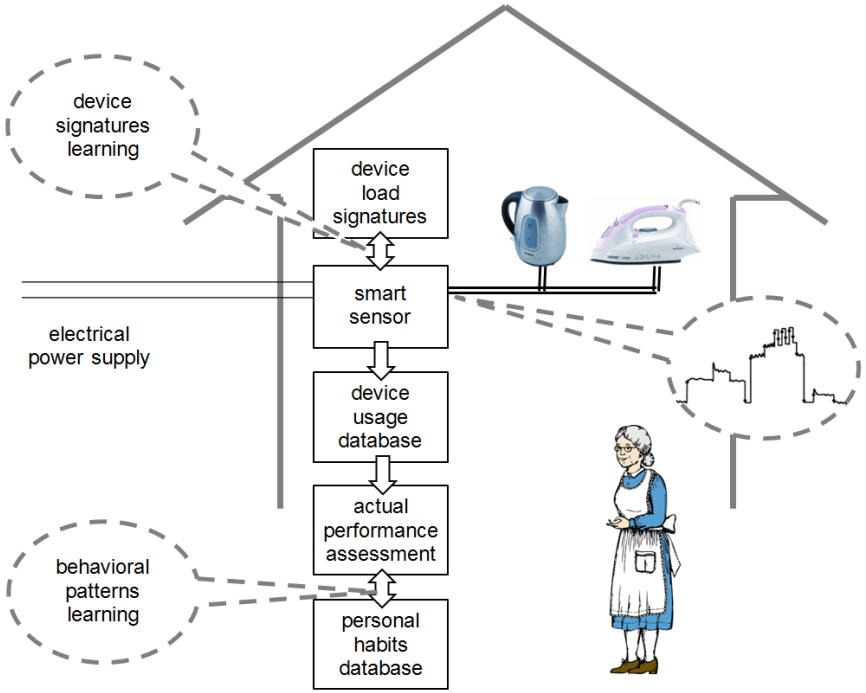
Augustyniak, P. Detection of Behavioral Data Based on Recordings from Energy Usage Sensor. (ICAISC 2016), Lecture Notes in Artificial Intelligence, Vol. 9693, pp. 137-146

Imperceptible Sensors

activity detection with smart power meter







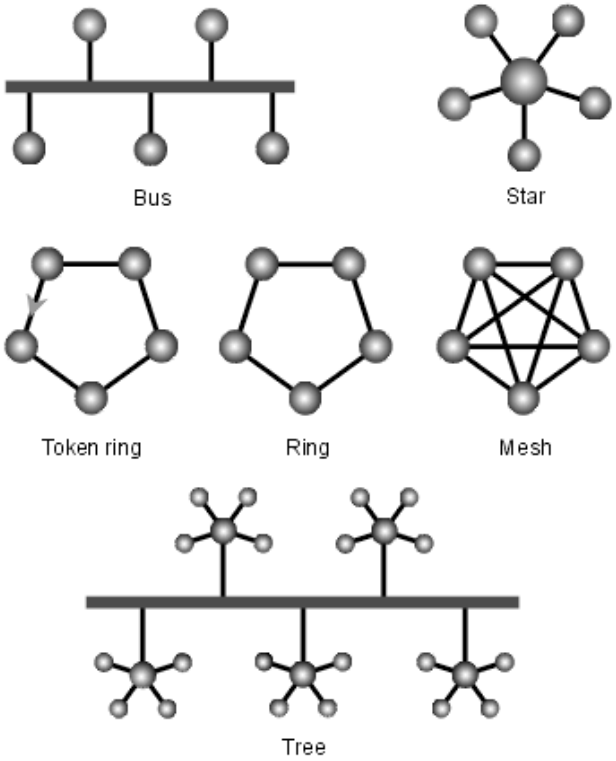
Sensors and Sensor Networks

1. Sensor Types and Characteristics
2. Intelligent sensors
3. Imperceptible Sensors
4. **Sensor Network**
5. Sensor Information Safety

Sensors and Sensor Networks

Sensor Network

Sensor network is a computer network with (intelligent) sensors



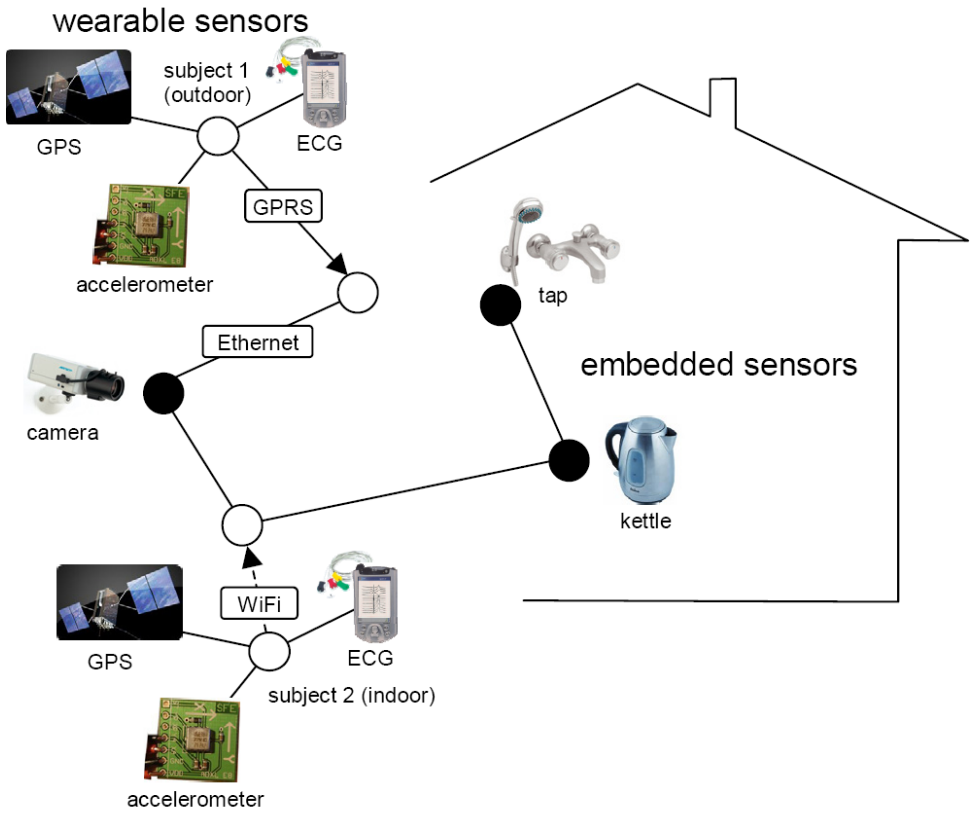
- data security must comply with medical requirements (VPN),
- quality of service must comply with medical requirements (fault-tolerance).

- wide area networks for connecting a mobile patient and enviromnetal data,
- local area networks for home recording
- personal (body) area network (BAN or BSN) for individual-related measurements

Sensors and Sensor Networks

- simple sensors with digital communication module,
- intelligent (programmable) sensors (two-way link)
- decision-making sensors (artificial intelligence of things)
- recursive network hierarchy (a node in main network is a hub in subnetwork)

Sensor Network



Sensor Network

WBAN (wireless body area network) Challenges (1):

*** Interoperability:** WBAN systems would have to ensure seamless data transfer across standards such as Bluetooth, ZigBee etc. to promote information exchange, plug and play device interaction. Further, the systems would have to be scalable, ensure efficient migration across networks and offer uninterrupted connectivity.

*** System Devices:** The sensors used in WBAN would have to be low on complexity, small in form factor, light in weight, power efficient, easy to use and reconfigurable. Further, the storage devices need to facilitate remote storage and viewing of patient data as well as access to external processing and analysis tools via the Internet.

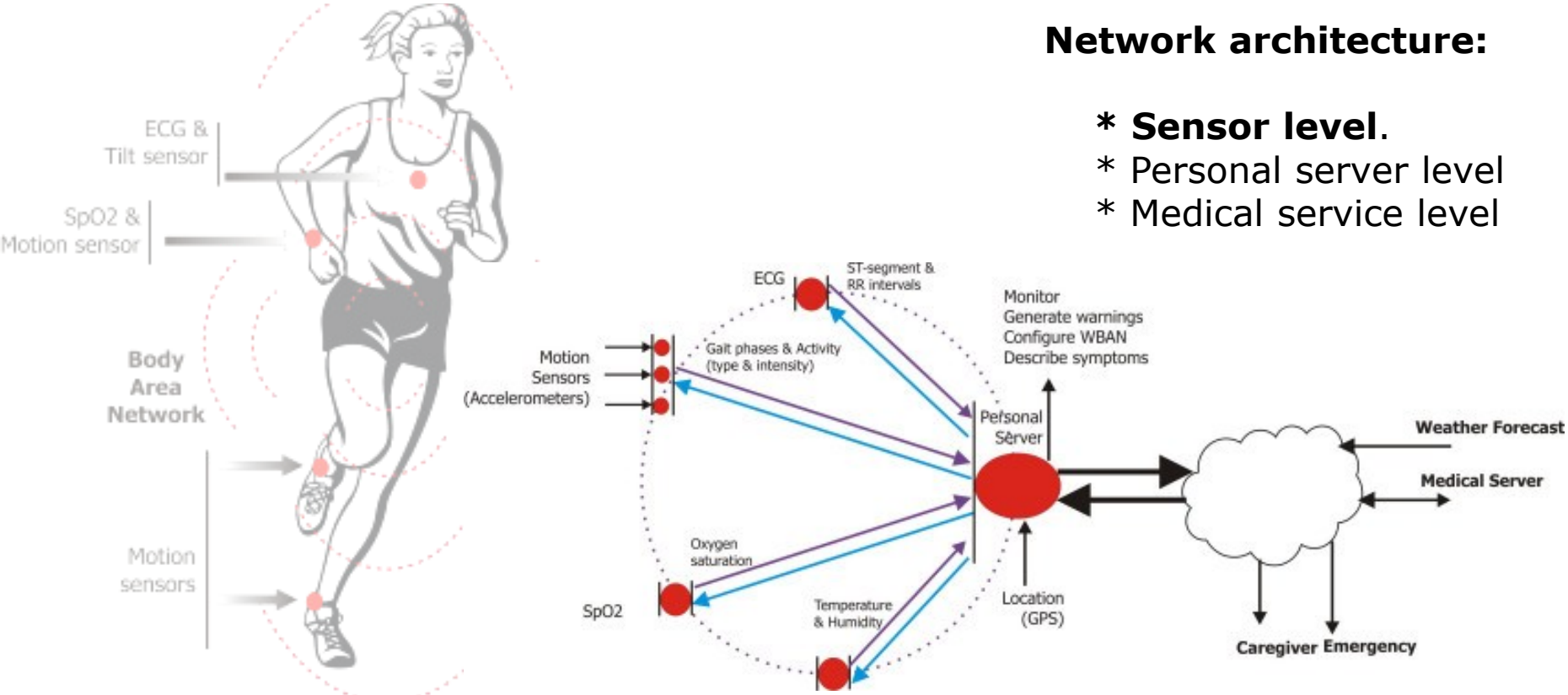
Sensor Network

WBAN (wireless body area network) Challenges (2):

*** System and device-level security**: Considerable effort would be required to make BAN transmission secure and accurate. It would have to be made sure that the patient's data is only derived from each patient's dedicated BAN system and is not mixed up with other patient's data. Further, the data generated from WBAN should have secure and limited access.

*** Invasion of privacy:** People might consider the WBAN technology as a potential threat to freedom, if the applications go beyond 'secure' medical usage. Social acceptance would be key to this technology finding a wider application.

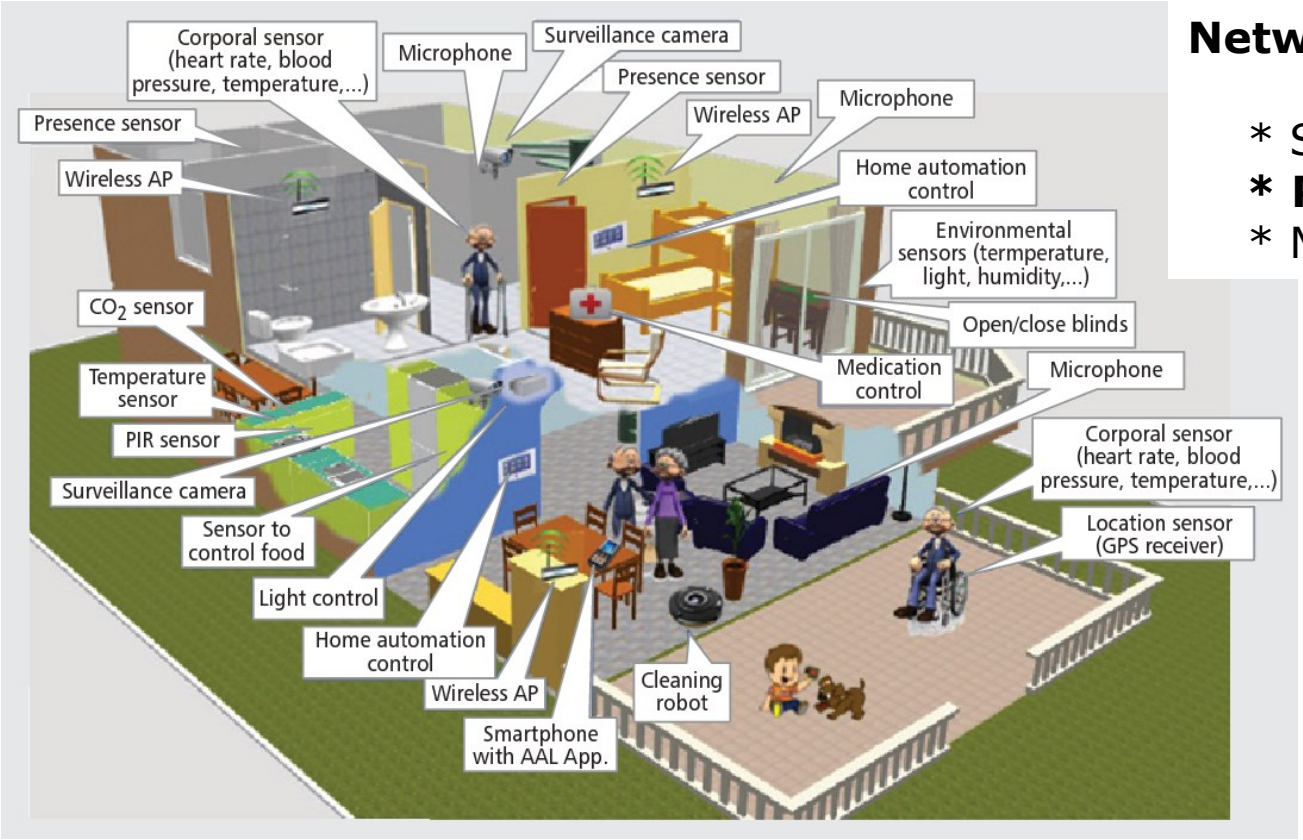
Sensor Network



Network architecture:

* **Sensor level**.
* Personal server level
* Medical service level

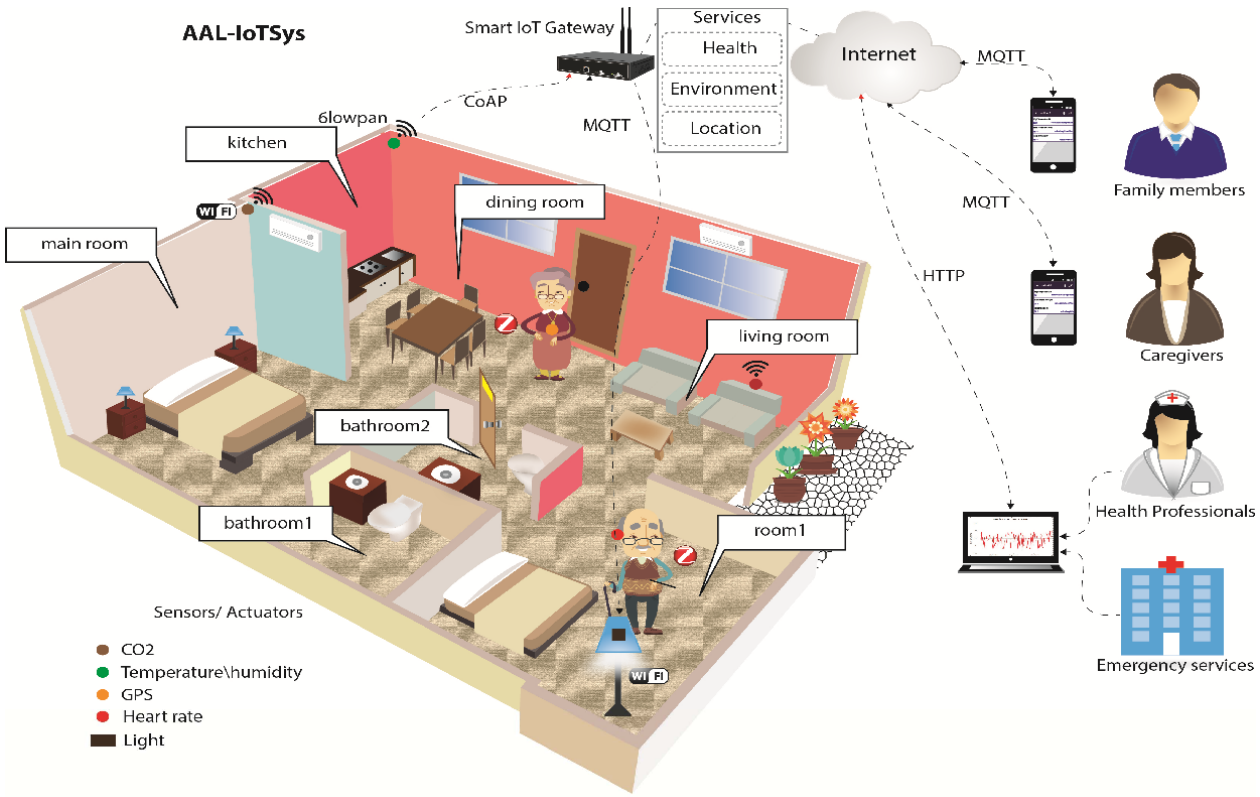
Sensor Network



Network architecture:

* Sensor level.
* **Personal server level**
* Medical service level

Sensor Network



Network architecture:

* Sensor level.
* Personal server level
* **Medical service level**

Sensors and Sensor Networks

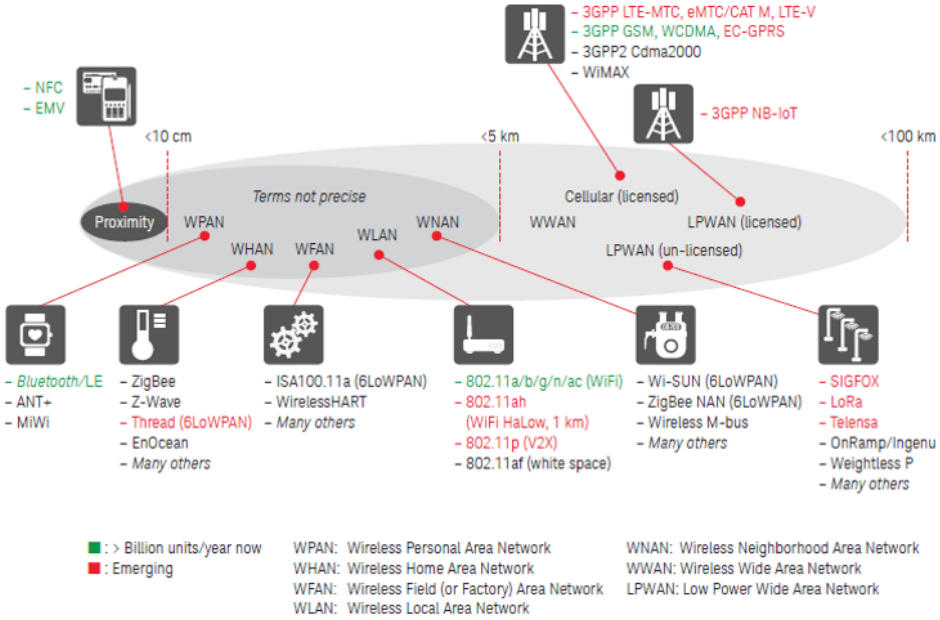
1. Sensor Types and Characteristics
2. Intelligent sensors
3. Imperceptible Sensors
4. Sensor Network
5. **Sensor Information Safety**

Sensors and Sensor Networks

Sensor Information Safety

Sensor network is established based on short range communication standards in unlicensed 2.4000 gigahertz (GHz) to 2.4835 GHz Industrial, Scientific, and Medical (ISM) frequency band according to:

- WiFi 802.11ac, 802.11b/g/n,
- ZigBee IEEE 802.15.4,
- Bluetooth IEEE 802.15.1

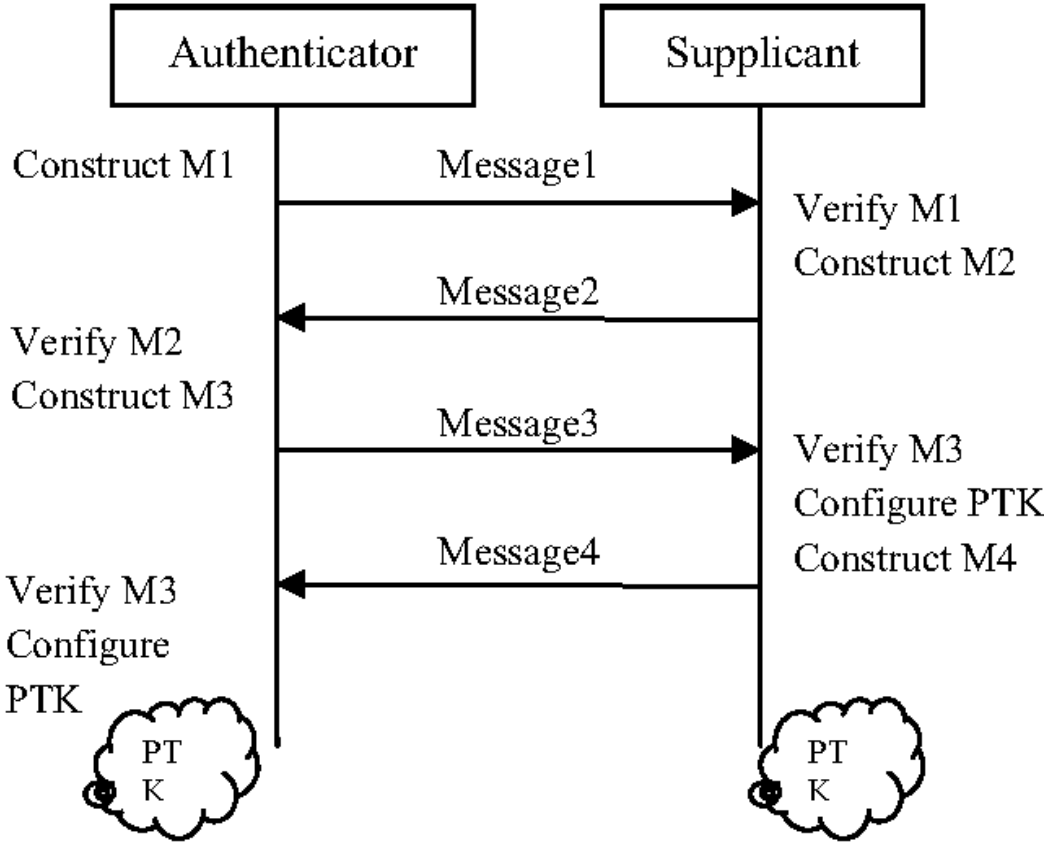


Sensor Information Safety

Example of WiFi pairing protocol.

WEP-WPA-WPA2 with dynamic 128b keys on packet/session/user levels

Gascón **Security in 802.15.4 and ZigBee networks** 2009



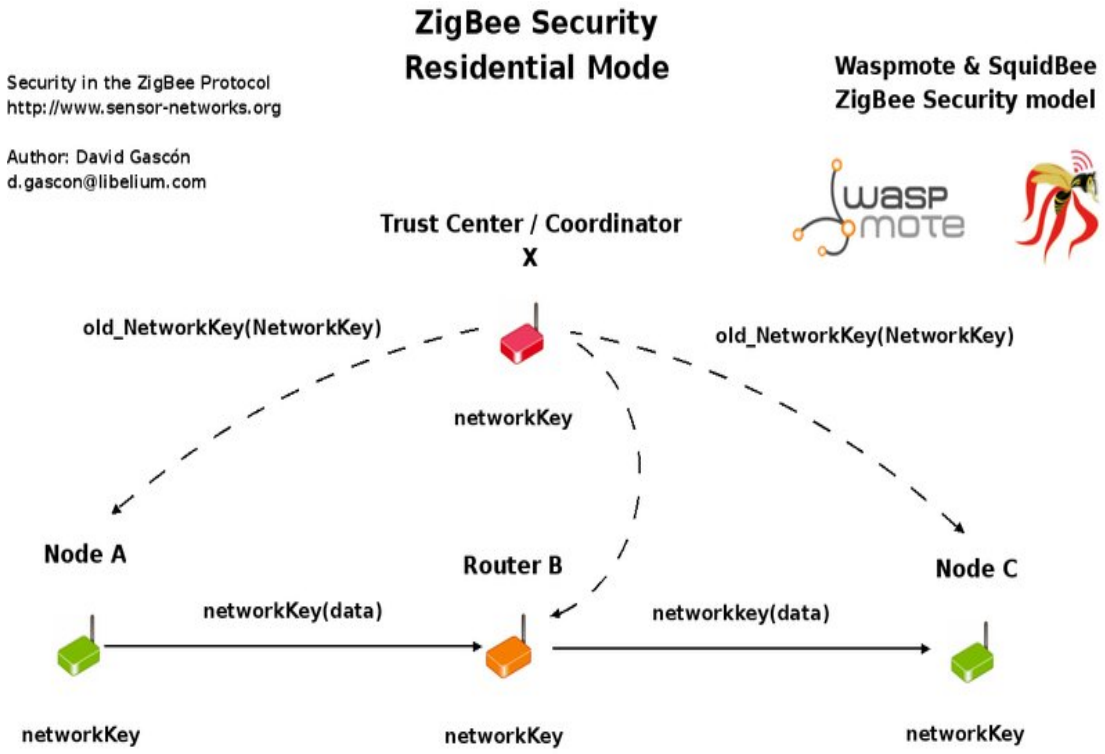
Sensors and Sensor Networks

Sensor Information Safety

Example of ZigBee pairing protocol.

ZigBee implements **two extra security layers** on top of the 802.15.4 one: the **Network** and **Application** security layers.

Gascón **Security in 802.15.4 and ZigBee networks** 2009



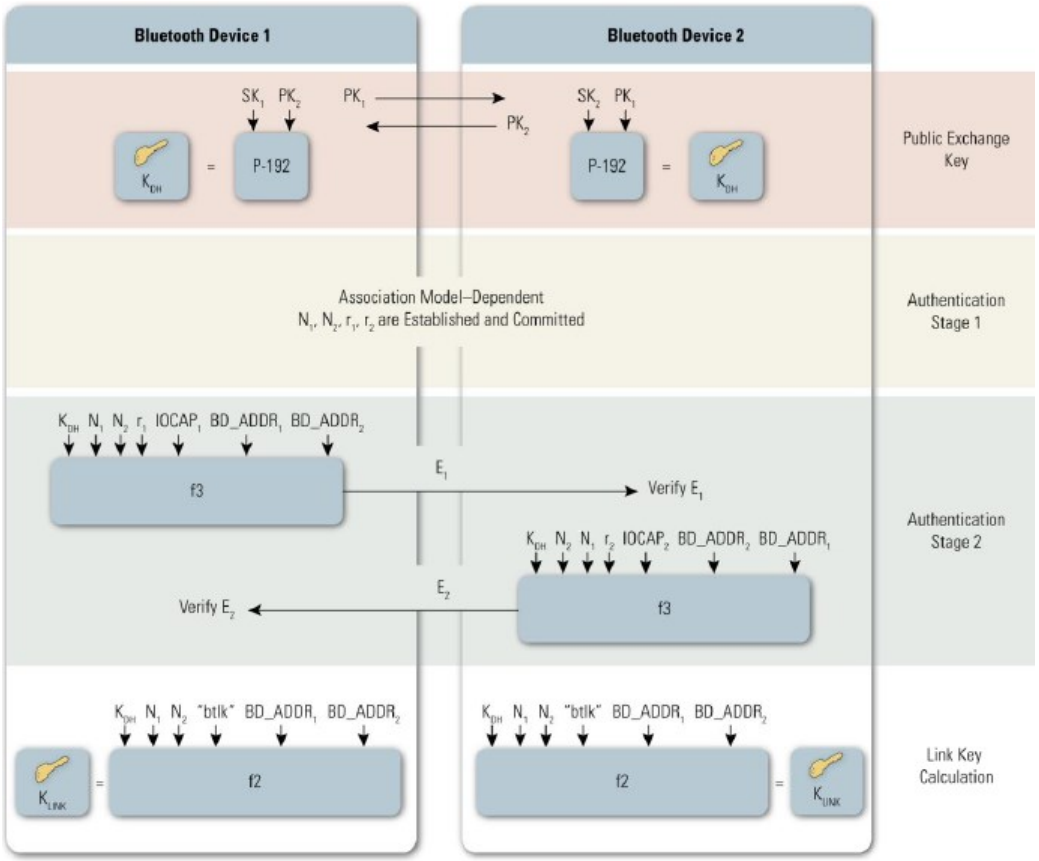
Sensors and Sensor Networks

Sensor Information Safety

Example of Bluetooth pairing protocol.

Link Key Establishment for Secure Simple Pairing

Padgete et al. Guide to Bluetooth Security 2012



Sensors and Sensor Networks

Sensor Information Safety

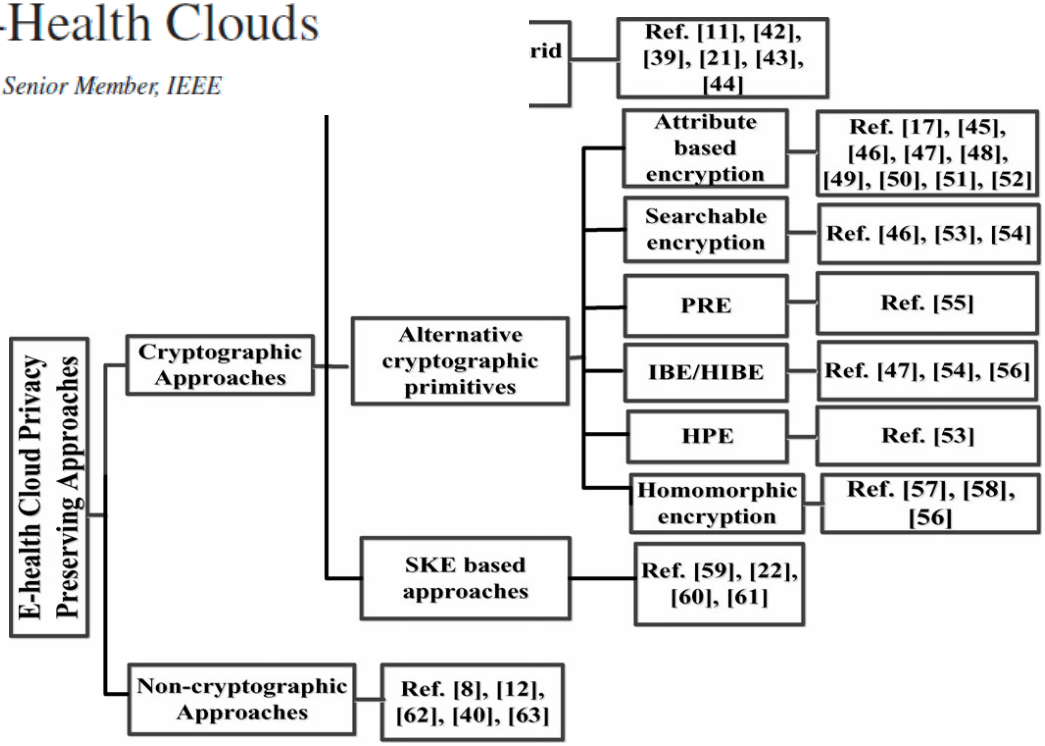
IEEE JOURNAL OF BIOMEDICAL AND HEALTH INFORMATICS, VOL. 18, NO. 4, JULY 2014 1431

A Review on the State-of-the-Art Privacy-Preserving Approaches in the e-Health Clouds

Assad Abbas and Samee U. Khan, *Senior Member, IEEE*

USA:

Health Insurance Portability and Accountability Act (HIPAA)



Digital Behavioral Record

1. **Physical Representation of Behavior**
2. Symbolic Representation of Behavior

Digital Behavioral Record

Physical Representation of Behavior

Advantages:

- ease to record (no processing needed),
- no data loss (any manipulation may be done later).

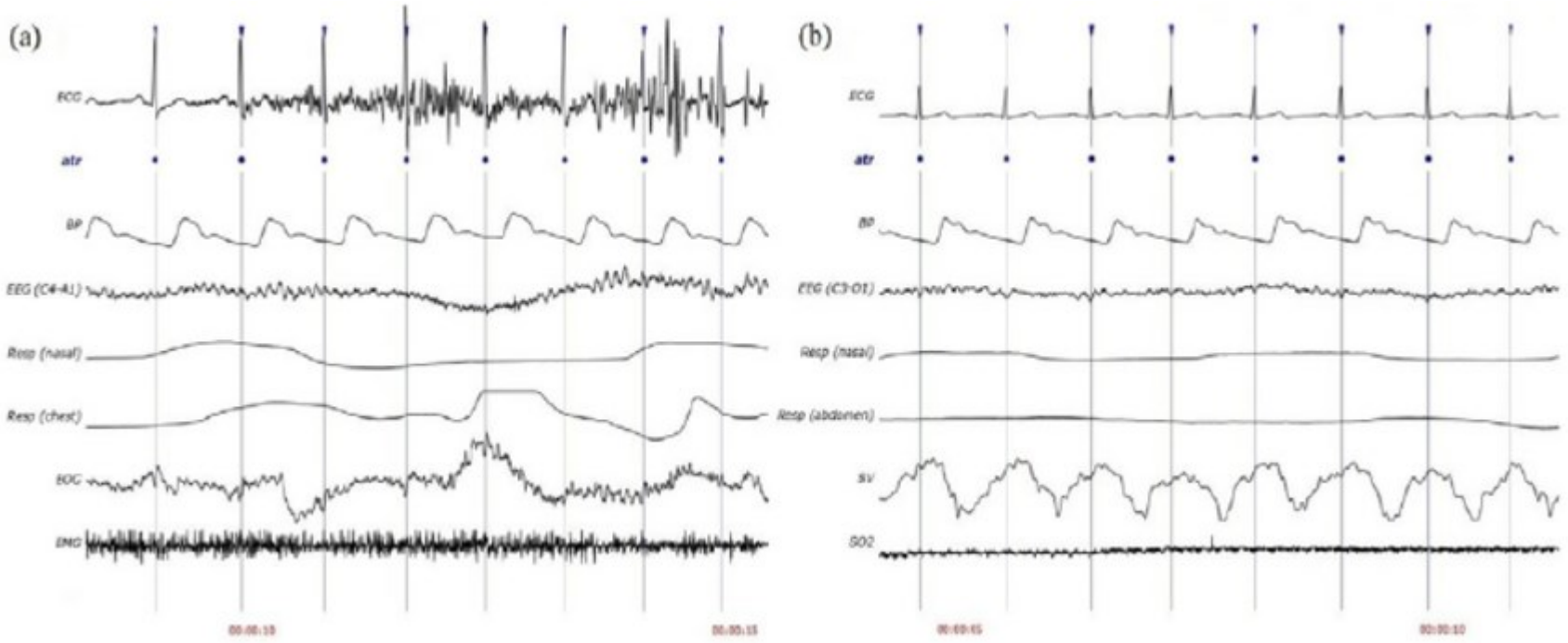
Drawbacks:

- different phenomena representation scales and units,
- permanent and optional sensors and data streams,
- continuous or event-related data,
- hierarchy of measurements in terms of importance and reliability,
- various data formats: images, signals, isolated values etc.
- delay of data availability.

Digital Behavioral Record

Physical Representation of Behavior

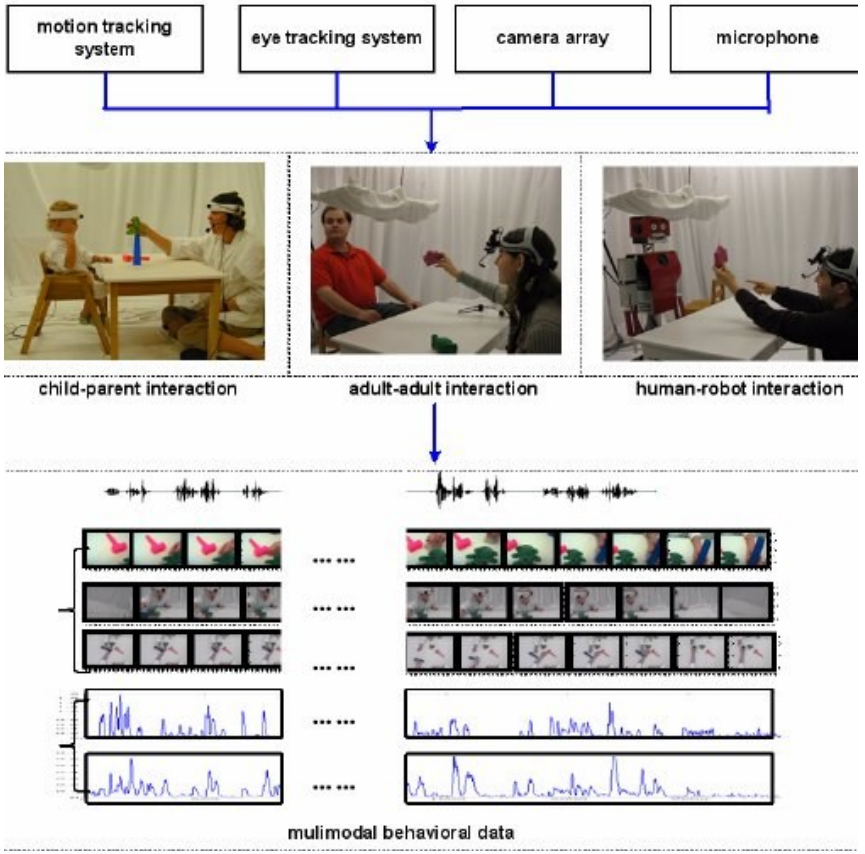
1. Multimodal record, physiological parameters



Digital Behavioral Record

Physical Representation of Behavior

2. Multimodal record, audiovisual parameters



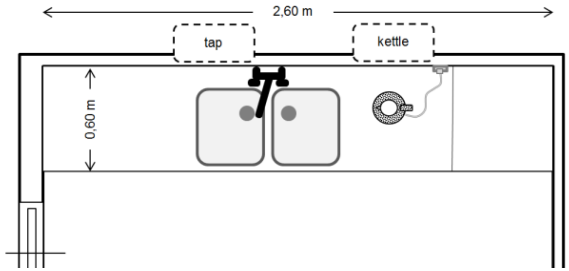
Digital Behavioral Record

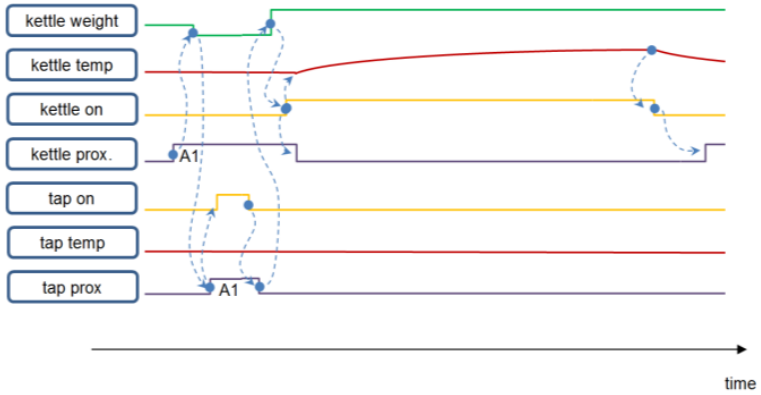
1. Physical Representation of Behavior
2. **Symbolic Representation of Behavior**

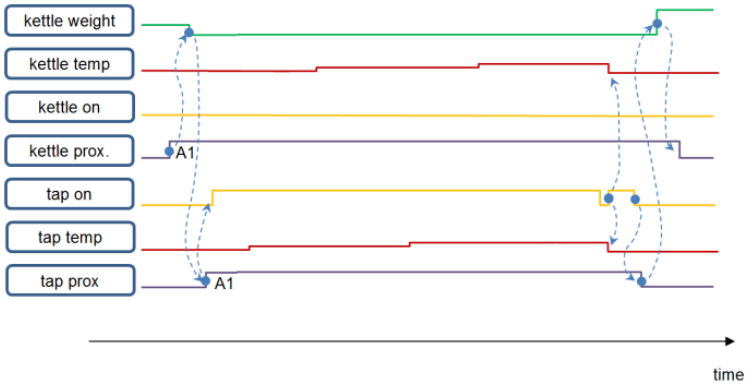
Digital Behavioral Record

Symbolic Representation of Behavior

Case 1: binary detection of action





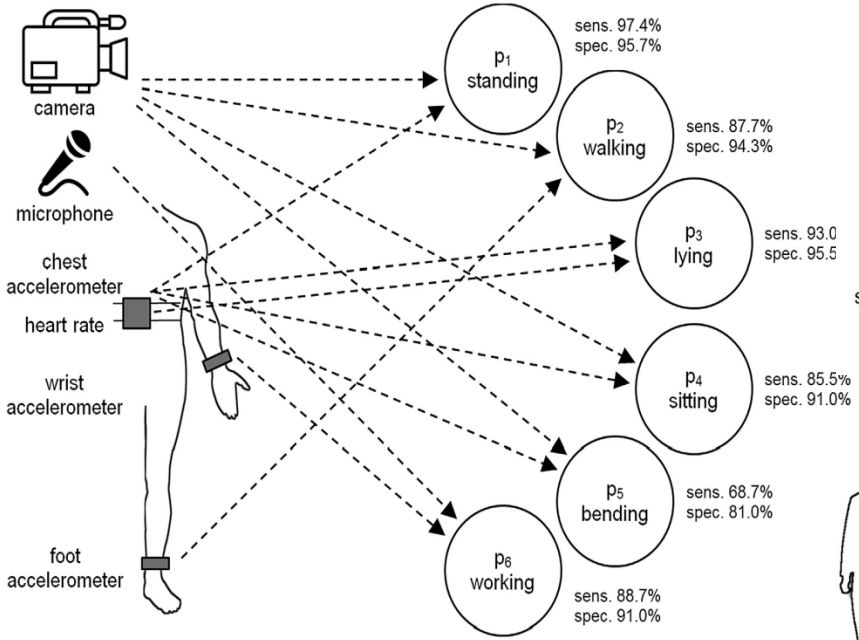


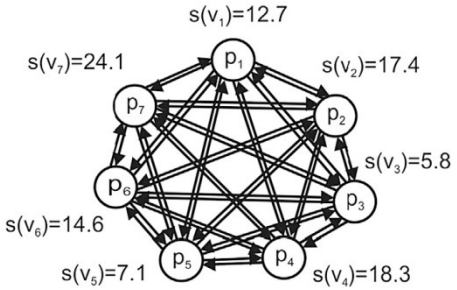
Augustyniak P., Kantoch E., Turning Domestic Appliances Into a Sensor Network for Monitoring of Activities of Daily Living, *J. Med. Imaging Health Inf.* 5, 2015, pp.1662-1667

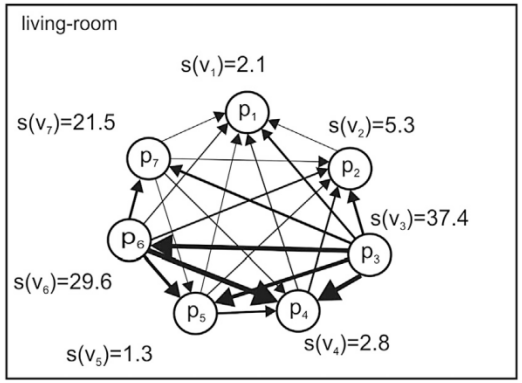
Digital Behavioral Record

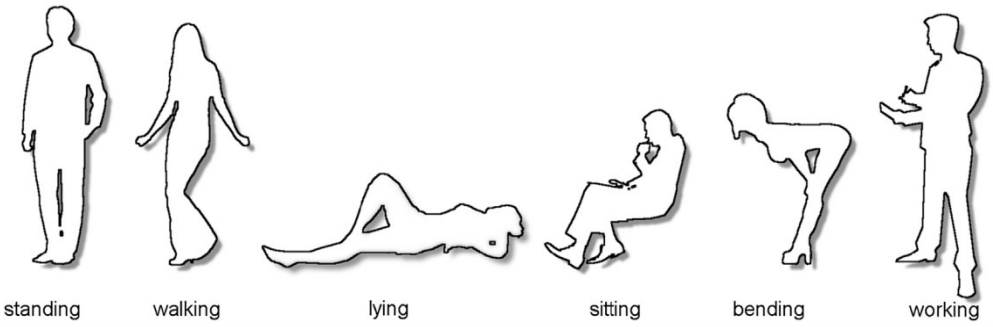
Symbolic Representation of Behavior

Case 2: individual fuzzy detection of actions and graph representation







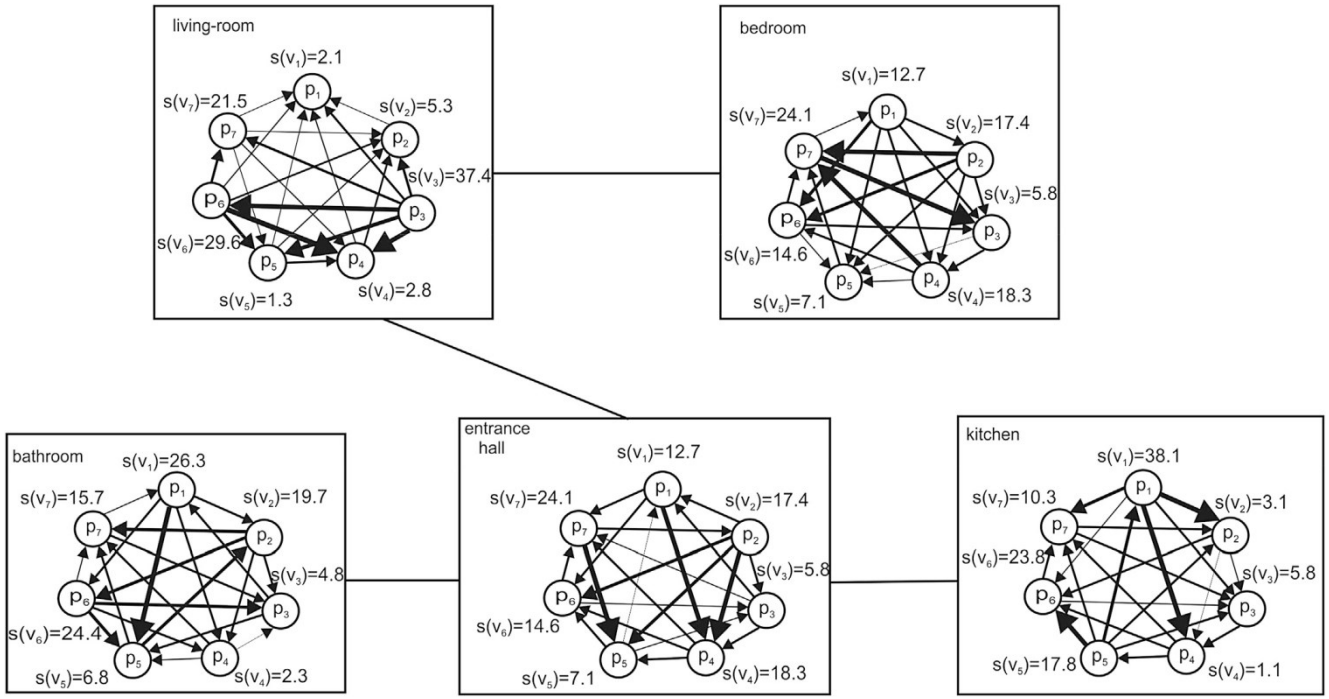


Augustyniak P., Slusarczyk G.: Graph-based representation of behavior in detection and prediction of daily living activities, *Computers in Biology and Medicine* 95 (2018) 261–270

Digital Behavioral Record

Symbolic Representation of Behavior

Case 2: participation state-space graph of behavioral patterns in the context of the layout of the considered apartment.



Symbolic Representation of Behavior

Case 3: application of percept sequences and ontologies to recognition and prediction of human action.

Definition 1. Percept – Assuming that the subject of an activity is *m*, an action is *a*, a pose is *p*, and nearby objects are *Os*, then a percept *p* is composed as follows:

$p = \{m, a, p, Os\}$,
$Os = \{[o1, o1\_state],[o2, o2\_state],\ldots, [oj, oj\_state],\ldots,[on, on\_state]\}$
$oj\_state \in \{on, off\}$

Os expresses the operation status of appliances in all objects around the subject of activity as on or off. For example, [TV, on] or [TV, off] represents the operation status of TV.

Definition 2. Percept Sequence – When a percept *p* recognized at a specific time *t* is given, a percept sequence *ps* is composed as follows.

$ps = \{<t1, p1>, <t2, p2>,\ldots,<tn, pn>\}, t1<t2<\ldots<tn$

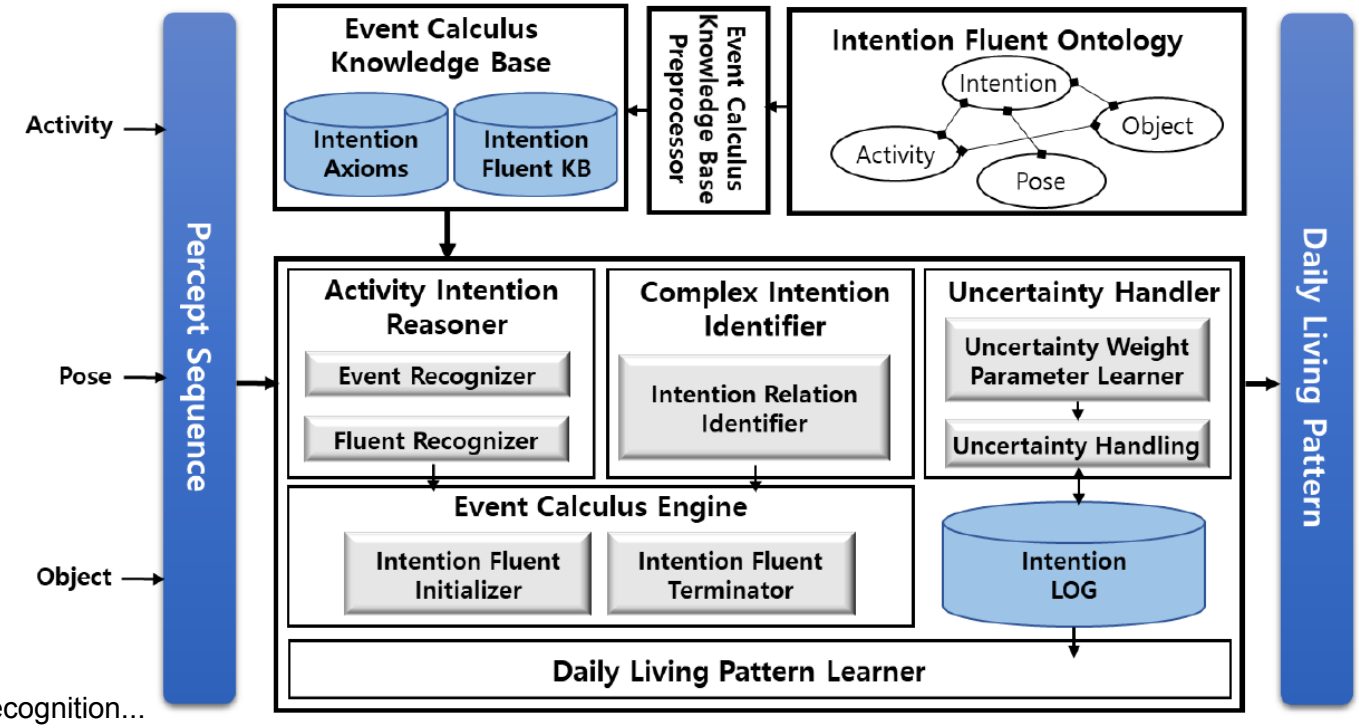
An action means doing something by moving the body, whereas a pose means the shape of the body when performing an action. The activity intention inferred based on a percept—composed of an action, a pose, and surrounding objects—means that a person performs with a certain will.

Kim J.-M. et al.: An approach for recognition of human's daily living patterns using intention ontology and event calculus, Expert Systems With Applications 32, 2019

Digital Behavioral Record

Symbolic Representation of Behavior

Case 3: application of percept sequences and ontologies to recognition and prediction of human action.



Kim J.-M. et al.: An approach for recognition...

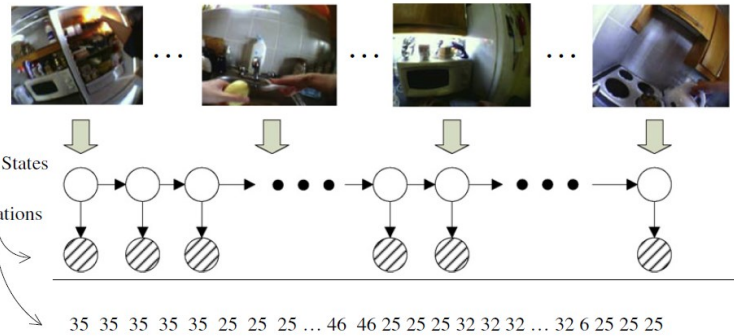
Identifying and Predicting Human Actions

Several approaches to identifying and predicting human actions:

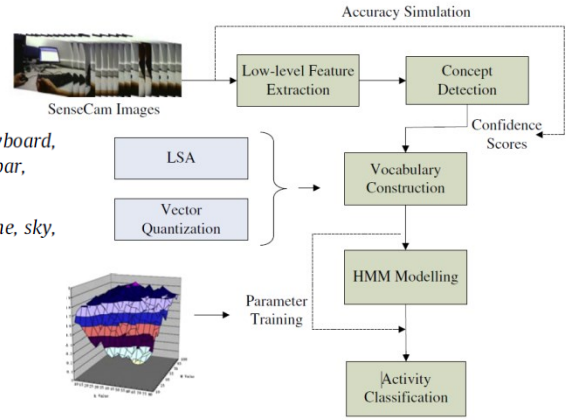
- State Machine,
- Hidden Markov Modells,
- Web Ontology Language,
- Artificial Intelligence for habits recognition
- ...

Identifying and Predicting Human Actions

Example 1: Wearable wideo camera logs with Latent Semantic Analysis



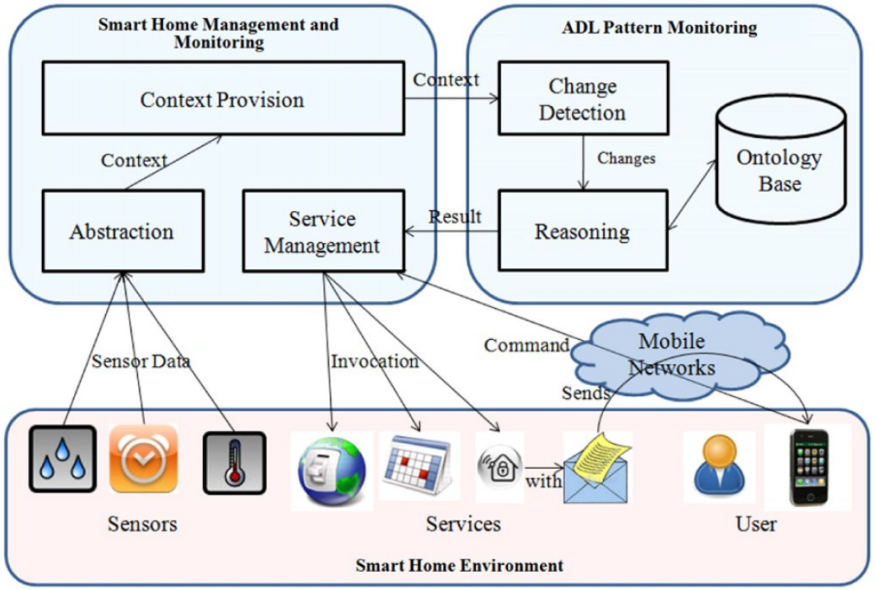
Objects	*plate, cup, cutlery, bowl, glass, bottle, milk, drink, fridge, microwave, cooker, water, cloth, clothes, glove, soap, hanger, screen, keyboard, monitor, TV, remote control, basket, trolley, plastic bag, mobile phone, phone screen, book, newspaper, notebook, paper, handle bar, steering wheel, car, bus, bicycle, pet, road sign, traffic light, cat, yellow pole, chair, laptop, projector, pram/buggy*
Scene/settings/ site	*indoor, outdoor, office, kitchen, table, sink, basin, toys, shelf, cashier, door, building, fruit, vegetable, deli, food, road, path, cycle lane, sky, tree, dark, window, inside bus, shop, inside car, projection*
People	*face, people, group, child, hand, finger*
Event	*hand washing, hanging clothes, hand gesture, finger touch, page turning, presentation, taking notes*

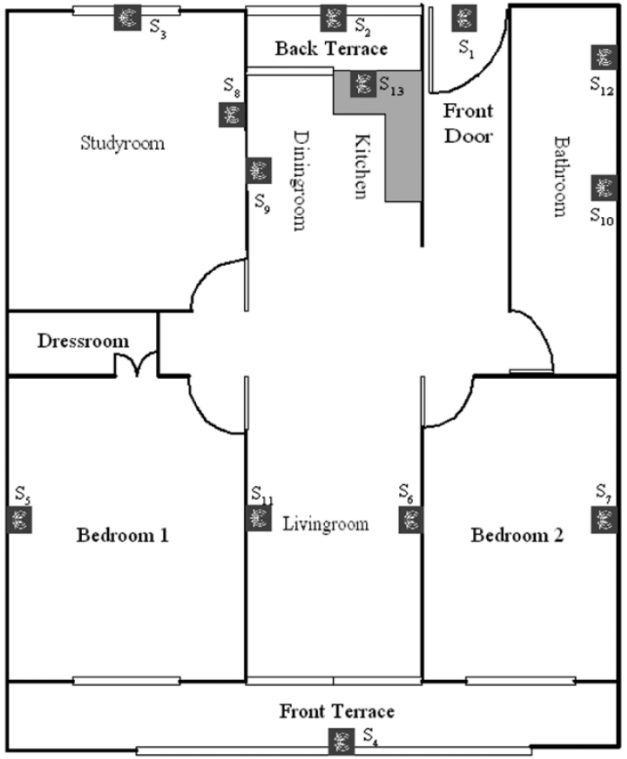


Peng Wang, Alan F. Smeaton Using visual lifelogs to automatically characterize everyday activities, Information Sciences 230 (2013) 147–161

Identifying and Predicting Human Actions

Example 2: Recognizing Activities of Daily Living by pattern matching

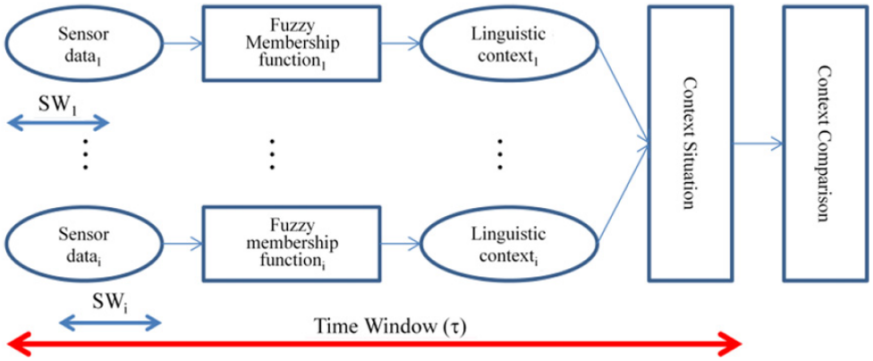


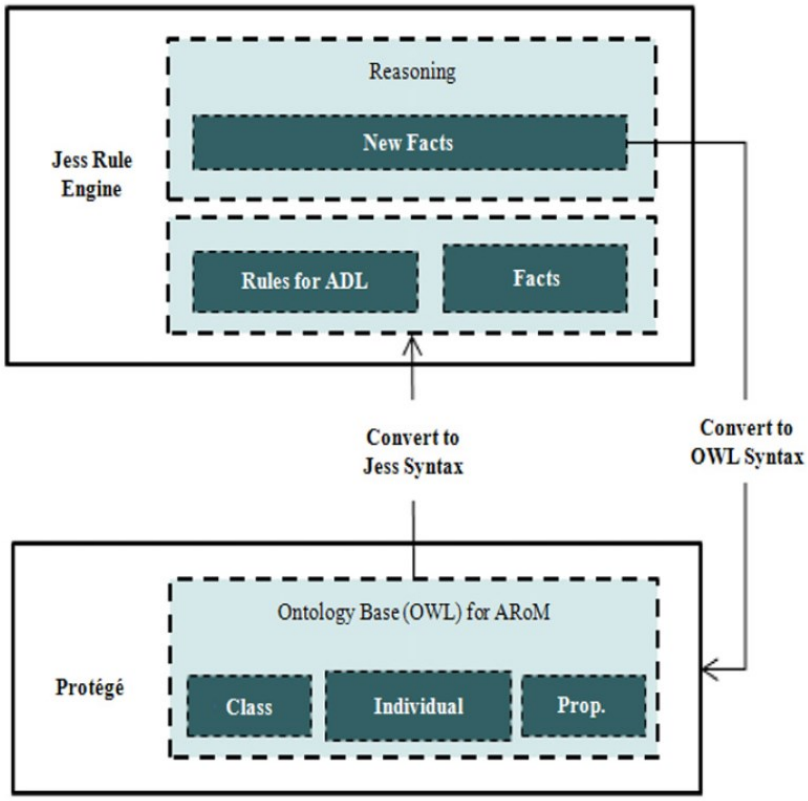


Ihn-Han Bae An ontology-based approach to ADL recognition in smart homes Future Generation Computer Systems 33 (2014) 32–41

Identifying and Predicting Human Actions

Example 2: Recognizing Activities of Daily Living by pattern matching

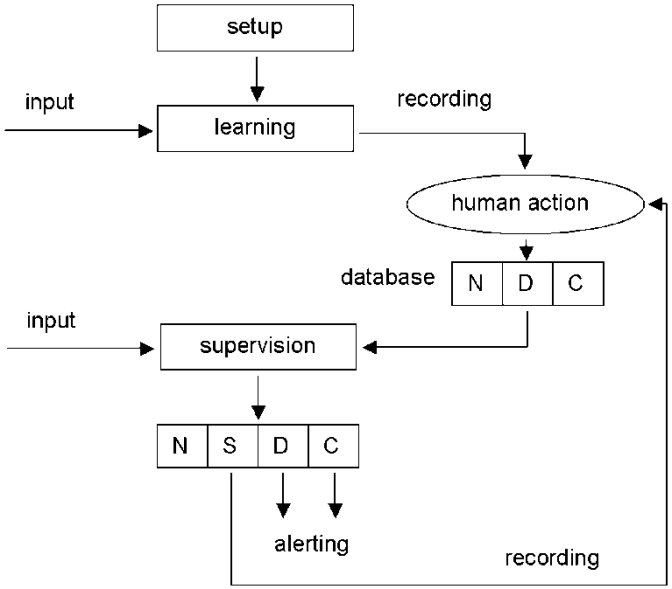


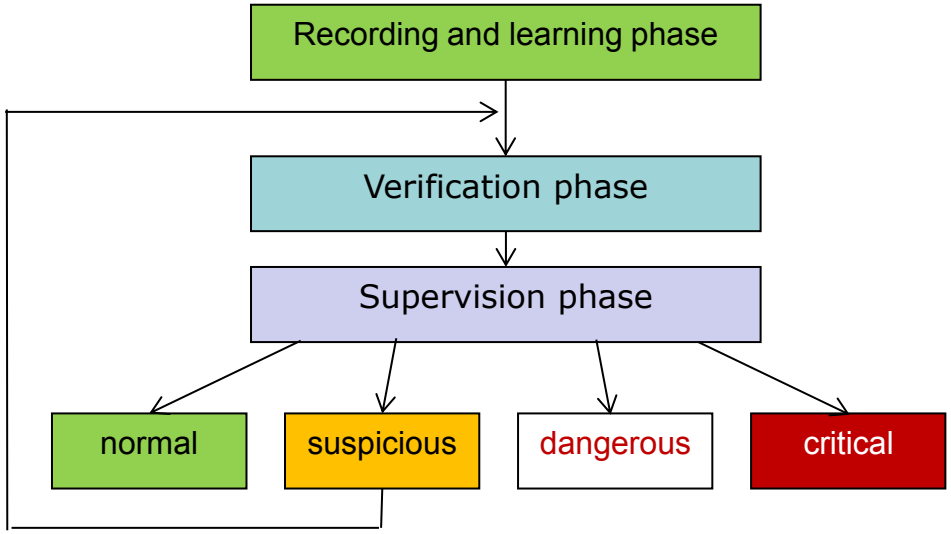


Ihn-Han Bae An ontology-based approach to ADL recognition in smart homes Future Generation Computer Systems 33 (2014) 32–41

Identifying and Predicting Human Actions

Example 3: Use of Artificial Intelligence for habits recognition



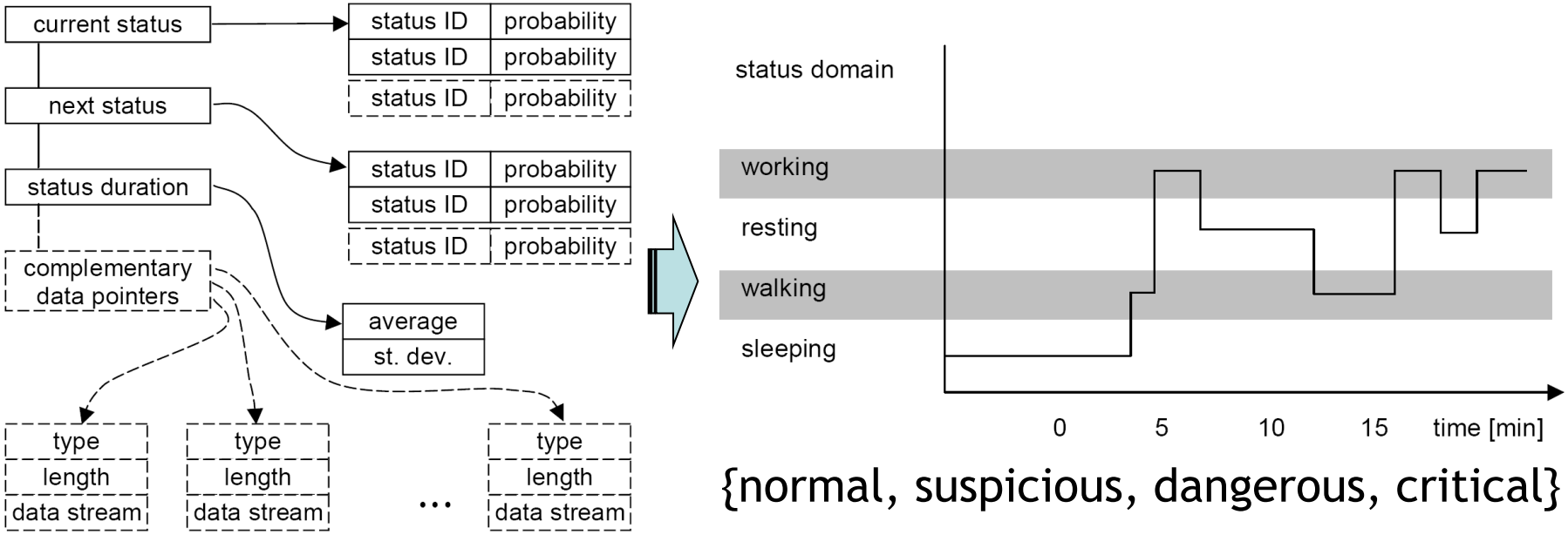


- adaptation to different behavioral habits of subjects
- evolution with changes of subject health and limitations
- easy correction by human supervisor

Augustyniak, P. Intelligent Sensing and Learning for Assisted Living Applications [in:] Hippe, ZS; Kulikowski, JL; Mroczek, T; Wtorek, J. Human-computer Systems Interaction: Backgrounds and Applications 3, 2014 pp. 155-166

Identifying and Predicting Human Actions

Example 3: Use of Artificial Intelligence for habits recognition



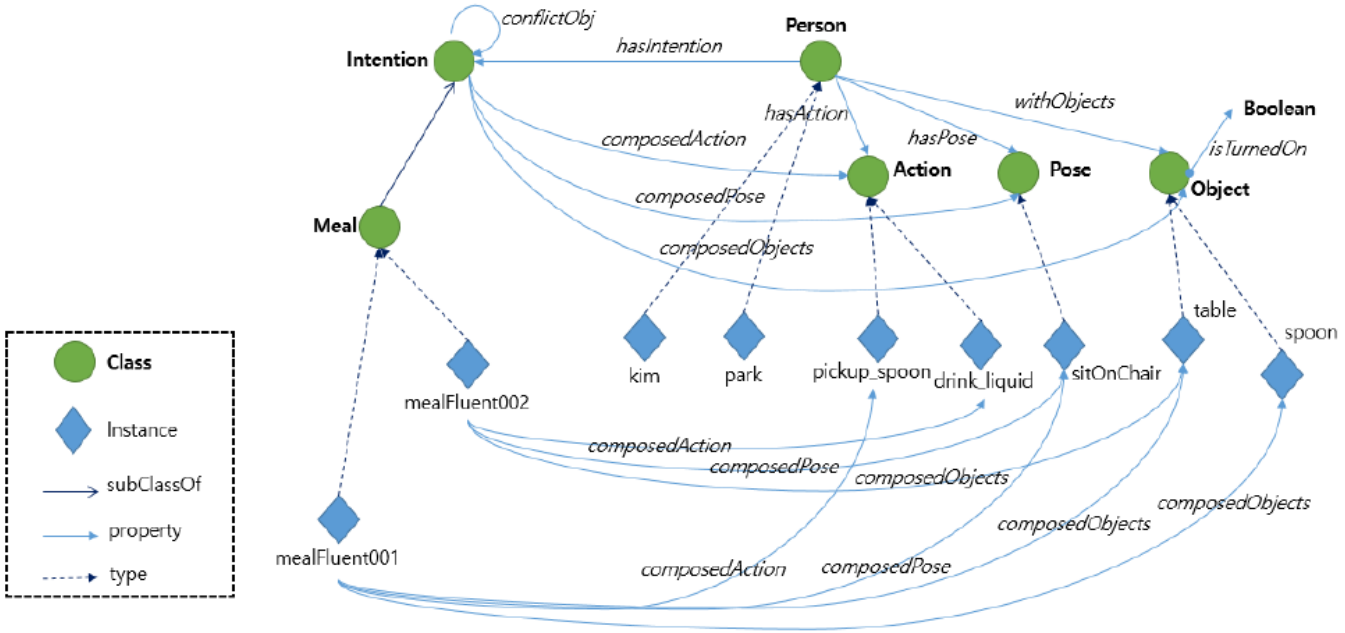
{normal, suspicious, dangerous, critical}

Augustyniak, P. Intelligent Sensing and Learning for Assisted Living Applications [in:] Hippe, ZS; Kulikowski, JL; Mroczek, T; Wtorek, J. Human-computer Systems Interaction: Backgrounds and Applications 3, 2014 pp. 155-166

temporal descriptors of subject's status are transformed to actigrams actions are categorized by an AI-based classifier

Identifying and Predicting Human Actions

Example 4: application of percept sequences and ontologies to recognition and prediction of human action



Kim J.-M. et al.: An approach for recognition of human's daily living patterns using intention ontology and event calculus, Expert Systems With Applications 32, 2019

Perspectives and challenges

Technical challenges:

- new sensors and new sensing paradigms e.g. sweat, food content etc.
- combining diagnostics with therapy (e.g. sensors with drug delivery),
- disease-dependent remote programmability of sensors,
- artificial (distributed) intelligence of sensors,
- sensing infrastructures following the mobile human,
- integration of medical sensing with home automation,
- modular easy-to-operate sensor infrastructures.

Perspectives and challenges

Healthcare challenges:

- regulations of cyber security for medical remote sensing,
- wider access to lifestyle monitoring for those who want (insurance discounts),
- combining diagnostics with prevention (cost efficiency),
- medical backgrounds for lifestyle profiling,
- home-care equivalents of medical tests,
- prescription and home delivery of (tele)diagnostic modules,
- including emotion recognition to sensing modes and psychiatry to telecare,

Bibliography

1. Augustyniak P. Tadeusiewicz R (2009) Ubiquitous Cardiology: emerging wireless telemedical applications, Hershey, New York
2. Augustyniak P (2010) Personalized building-embedded and wearable monitoring infrastructures with mediated data transfer, Proceedings of the 32nd annual international conference of the IEEE Engineering in Medicine and Biology Society, pp. 2121–2127
3. Augustyniak P, Smoleń M, Broniec A, Chodak J (2010) Data integration in multimodal home care surveillance and communication system. In: Pietka, E., Kawa, J. (eds.) Information technologies in biomedicine 2. Springer, Berlin Heidelberg New York, pp. 391-402
4. Smoleń M, Czopek K, Augustyniak P (2010) Sleep evaluation device for home-care. In: Pietka E, Kawa J (eds.) Information technologies in biomedicine 2. Springer, Berlin Heidelberg New York, pp. 367-378
5. Ślusarczyk G, Augustyniak P (2010) A graph representation of subject's time-state space. In: Pietka E, Kawa J (eds.) Information technologies in biomedicine 2. Springer, Berlin Heidelberg New York, pp. 379-390
6. Augustyniak P (2011) Compound Personal and Residential Infrastructure for Ubiquitous Health Supervision. In: Hippe ZS, Kulikowski JL, Mroczek T (eds.) Human-Computer Systems Interaction. Backgrounds and Applications 2, Springer, Berlin Heidelberg New York pp. 523-538.
7. Augustyniak, P., (2011) Wearable wireless heart rate monitor for continuous long-term variability studies. J. of Electrocardiology 44(2), 2011, 195-200
8. Mikrut Z, Pleciak P, Smoleń M (2012) Combining Pattern Matching and Optical Flow Methods in Home Care Vision System. Lecture Notes in Computer Science, Vol. 7339, Information Technologies in Biomedicine, pp. 537-548
9. Kańtoch E, Augustyniak P (2012) Human activity surveillance based on wearable body sensor network in: Proc. 39 Computing in cardiology pp. 325–328.
10. Augustyniak P (2012) Layered design of an assisted living system for disabled, In: Information Technologies in Biomedicine 3 Piętka E, Kawa J (eds.) Springer-Verlag, pp. 498–509.

Bibliography

11. Augustyniak P (2013) Description of Human Activity Using Behavioral Primitives, In: Burduk R. et al. (eds.) Proceedings of the 8th International conference on Computer Recognition Systems CORES 2013, Heidelberg, Springer, pp. 661–670.
12. Augustyniak, P. (2014) Intelligent Sensing and Learning for Assisted Living Applications [in:] Hippe, ZS; Kulikowski, JL; Mroczek, T; Wtorek, J. Human-computer Systems Interaction: Backgrounds and Applications 3, pp. 155-166
13. Augustyniak P., Kantoch E., (2015) Turning Domestic Appliances Into a Sensor Network for Monitoring of Activities of Daily Living, J. Med. Imaging Health Inf. 5, 2015, pp.1662-1667
14. Augustyniak, P. (2016) Detection of Behavioral Data Based on Recordings from Energy Usage Sensor. (ICAISC 2016), Lecture Notes in Artificial Intelligence, Vol. 9693, pp. 137-146
15. Przybylo, J., Kantoch, E., Jablonski, M., Augustyniak, P., (2016) Distant measurement of plethysmographic signal in various lighting conditions using configurable frame-rate camera. Metrology and Measurement Systems, 23(4), pp. 579-592
16. Augustyniak P., Slusarczyk G.: (2018) Graph-based representation of behavior in detection and prediction of daily living activities, Computers in Biology and Medicine 95, 261–270
17. Lorenzo Scalise Non Contact Heart Monitoring http://cdn.intechweb.org/pdfs/27007.pdf
18. Thomas Niederhauser (et al.) Simultaneous Registration of ECG and Cardiac Motion by a Single Esophageal Probe. Computing in Cardiology 2013; 40:651-654 http://www.cinc.org/archives/2013/pdf/0651.pdf
19. Kei Ito, Yutaka Fukuoka, Gert Cauwenberghs, Akinori Ueno, Noncontact Sensing of Electrocardiographic Potential and Body Proximity by In-bed Conductive Fabrics Computing in Cardiology 2013; 40:523-526 http://www.cinc.org/archives/2013/pdf/0523.pdf
20. Poh M-Z, McDuff D.J. Picard R.W. Non-contact, automated cardiac pulse measurements using video imaging and blind source separation, OPTICS EXPRESS 18(10) http://web.media.mit.edu/~zher/papers/Poh-etal-OptExp.pdf
21. Li X, Chen J, Zhao G, Pietikainen M, Remote Heart Rate Measurement From Face Videos Under Realistic Situations, IEEE Conference on Computer Vision and Pattern Recognition, 2014, 4264 – 4271

AGH

AGH University of Science and Technology

100 LAT AGH

Department of Biocybernetics and Biomedical Engineering

Piotr Augustyniak

Eliasz Kańtoch
wireless communication

Jaromir Przybyło
visual systems
virtual reality

Piotr Szymczyk
internet of things
embedded syst.

Scientific work supported by the AGH University of Science and Technology grant no. 16.16.120.773

AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY

Multimodal Measurement Systems for Health and Behavior Analysis in Living Environment

Piotr Augustyniak

AGH - University of Science and Technology
Department of Biocybernetics and Biomedical Engineering

thank you for listening

Scientific work supported by the AGH University of Science and Technology grant no. 16.16.120.773