Feasibility of a multi-tier Cyber Physical System as a Self-Aware Entity

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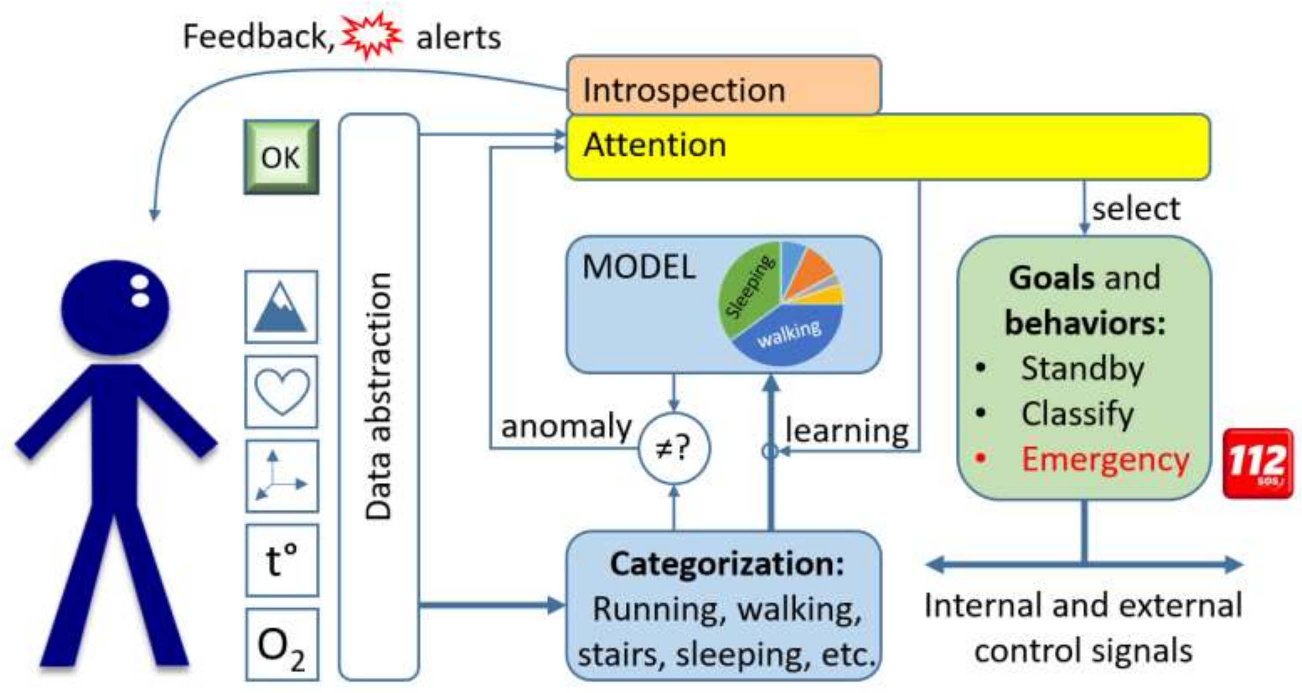
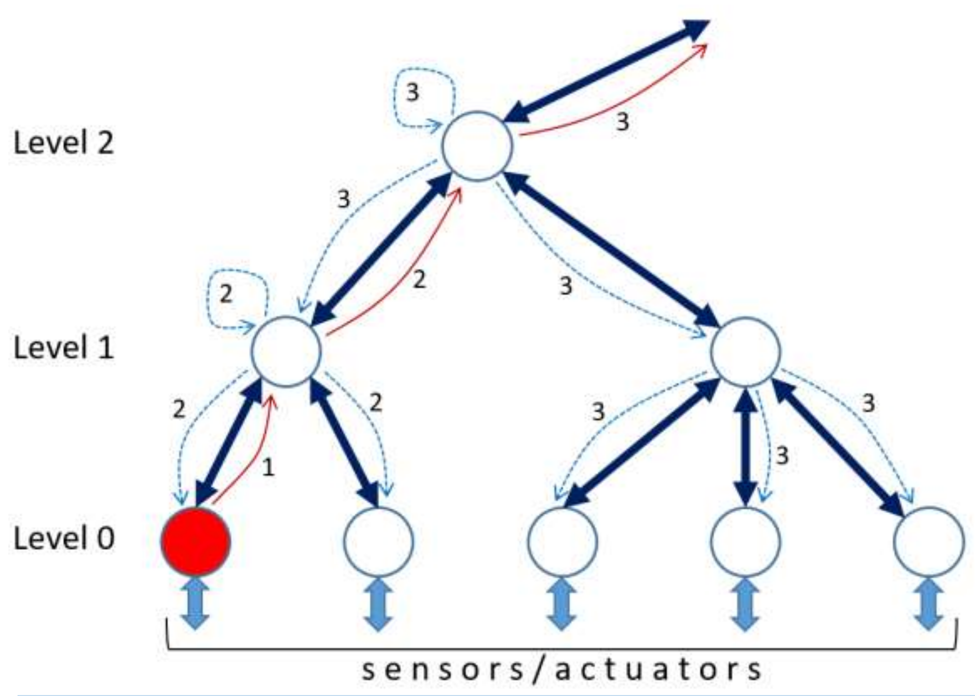
Abstract – In CPS self-awareness can be reached by hierarchically combining information over several processing levels. Based on sole use of a microcontroller with limited processing and memory capabilities a reasonable awareness level can be hardly achieved. For a case study an ARM based MCU (TM4C123G) has been chosen with 32KB of SRAM in a specific application domain - home patient monitoring. In [1] four levels of a CPS awareness are defined. While awareness levels 0 (controller) and 1 (PID-controller) are easily achievable on a regular microcontroller platform, the awareness level 2 (self-inspection) can be reached only partially due to memory limits. A higher level of awareness can be achieved at the second level in the computational hierarchy controller with more resources, especially with abundance of working memory to keep and run the dynamic model of the environment. The terminal level controllers are responsible for basic detection of the anomalous situation and delivering sensor data upwards with only a modest pre-processing. The approach enables to control the power consumption of the system - when the situation is stable and without remarkable changes, the controllers suppress the communication and maximize the usage of the sleep mode. An experimental the first tier controller is using Omron MEMS modules (D6T-44L-06) to detect the human presence and very roughly human repositioning in an infrared spectrum [2]. With two OMRON units 90 degrees of a visual field can be observed in arrangement 8x4 pixels (each pixel covering approximately 10 degrees of visual field both vertically and horizontally). The system is expected to become alerted if a significant anomaly or novelty appears, making all the approach to become the second generation of Home automation systems for an enhanced support for elderly and disabled people.



Architecture of self-aware health monitor [7]



Information and alertness broadcasting in a multi-tier CPS (Mist - Level 0, Fog - Level 1 and Cloud - Level 2). Solid red line – upward broadcasting of anomaly/alert signal, dashed blue line – broadcasting the attention across the level.

Anomaly detection capability of terminal nodes (increasing order in need of processing power):

1. Combinatorial temporal situation detection
   - fixed or temporal continuous linear predefined threshold
2. Predefined temporal model based
   - N-dimensional non-continuous threshold surface obtained analyzing off-line field data statistically
3. Predefined temporal model and supervised adaptive learning using e.g. reinforcement learning, e.g. Dynamic Bayesian Networks (DBN)
4. Temporal adaptive, environment model learned from a 'tabula rasa', non-supervised, e.g. Hierarchical Temporal memory

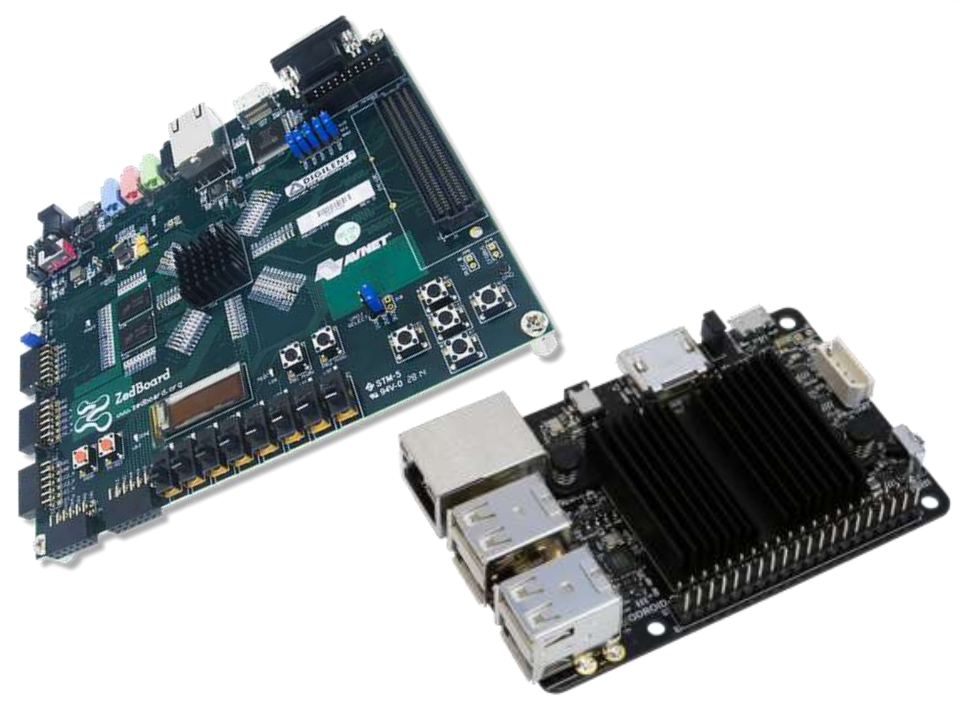
Temporal behaviour loops of a human:

1. Hourly [also Circadian rhythm, outdoor/indoor light condition dependent]
2. Weekdaily [accounting also holidays]
3. Yearly seasonal [actual climate dependent]
4. Personal recurrent events [e.g. birthdays]

In [3] an intensive study of a human behaviour is described using data collected in Smart-home over multiple years.

Available self-parameters of the terminal node:

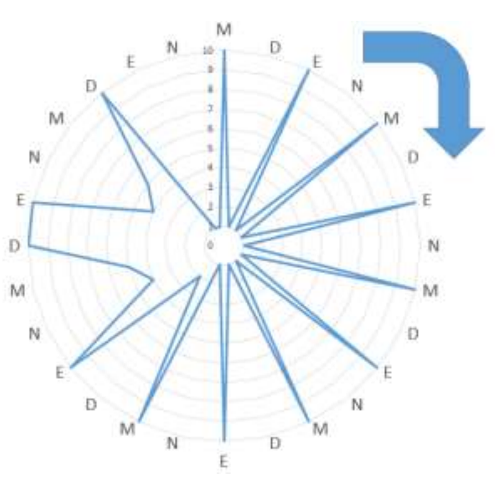
1. Self-temperature (board, microcontroller)
2. Battery voltage
3. Power consumption
4. Self-test status



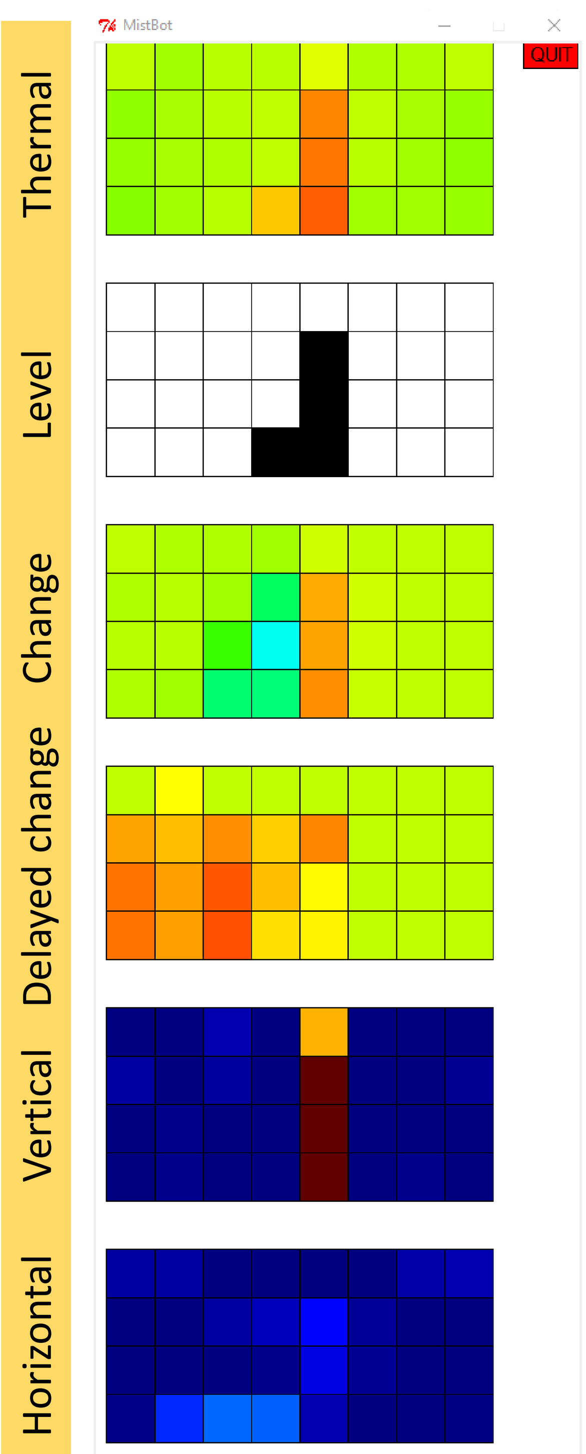
Under development: Fog level gateways (platforms) capable of Hierarchical Temporal Memory (HTM, Numenta Inc.) processing of fused input streams, continuous prediction and anomaly detection.

- ZedBoard Zynq-7000 (with XC7Z020 SoC FPGA) [12, Master thesis], and
- Odroid-C2 (single-board computer with 2GB of RAM) [Master thesis]

The thermal sensors of a **MistBot** (2 units) are registering privacy non-violating thermal picture of the subject in a visual sector 90°x 44.2°. The picture will be processed into change, delayed change, vertical and horizontal dynamic components using edge detection algorithms.
In the figure, the body is moving from left to right.



Hypothetical weekdaily activity of a working person.
(M – morning, D – day, E – evening, N – night)

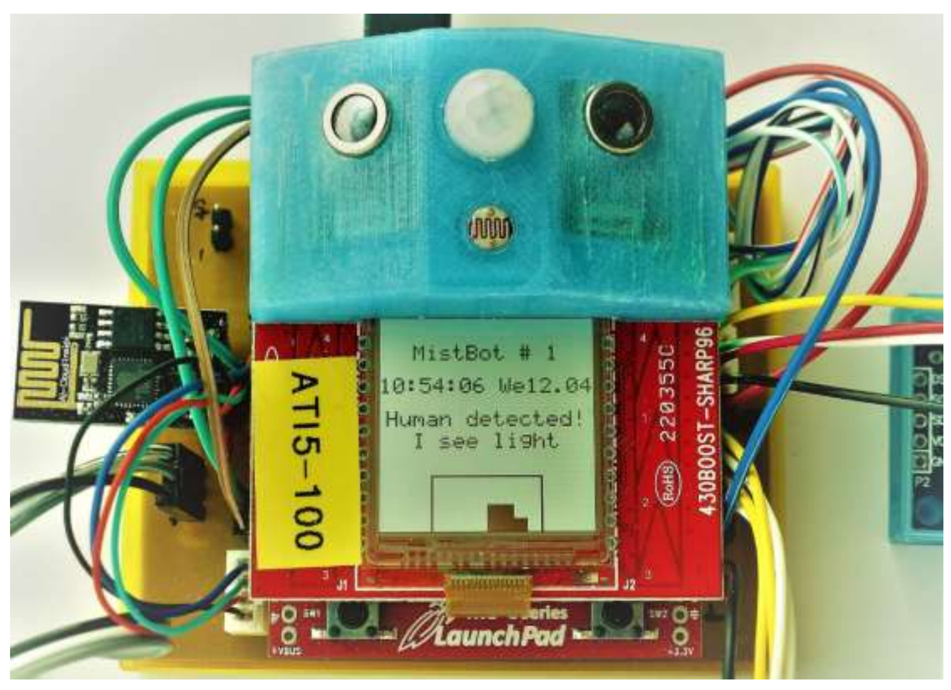


Attention serves as a basic set of mechanisms that underlie our awareness of the world and the voluntary regulation of our thoughts and feelings. [6]

Anatomy of three attentional networks: **alerting, orienting, and executive attention.**
Alerting is defined as achieving and maintaining a state of high sensitivity to incoming stimuli; **orienting** is the selection of information from sensory input; and **executive attention** involves mechanisms for monitoring and resolving conflict among thoughts, feelings, and responses. [6]

MistBot – Edge node	Current [mA]	Voltage [V]	Total power
2 x Omron MEMS D6T	10	5	0,05
PIR sensor	0,1	5	0,0005
Light sensor	0,33	3,3	0,00109
LCD screen	3,64E-06	3,3	1,20E-05
RGB LED (1/3 active)	6	5	0,03
CPU (20MHz)	15,7	5	0,0785
CPU (Hibernation)	0,45	5	0,00225
ESP8266 (full power)	170	3,3	0,561
ESP8266 (sleep)	0,5	3,3	0,00165

MistBot can reduce own power consumption around to mA range from the peak 200+ mA, controlling peripheral power lines and using sleep mode interruptible by the PIR-sensor.



MistBot - Edge node:

Based on TI TM4C123GXL LaunchPad (ARM Cortex-M4 microcontroller).

Inputs:

- Two Omron MEMS Thermal sensors D6T-44L
- PIR sensor
- Photo resistor (light sensor)
- RTC (DS1307)
- Pushbuttons, microswitch joystick for UI

Outputs:

- Serial interface
- WiFi ESP8266
- HCI: RGB LED (visual feedback)
- HCI: Mini speaker (audio alert and feedback)
- LCD module 430BOOST-SHARP96
- CMOS switches to control power of sensors

Future work: Implementing and deployment of the second level node of the system with full HTM functionality (Spatial and Temporal Pooling, Sparse Data Representation coding) to test *in vivo* environment learning capabilities of the system, communication between nodes and decision making at every node level.

Research papers:

[1] Axel Jantsch and Kalle Tammemäe. A framework of awareness for artificial subjects. In Proceedings of the 2014 International Conference on Hardware/Software Codesign and System Synthesis, CODES '14, pages 20:1–20:3, New York, NY, USA, 2014. ACM.
[2] Kalle Tammemäe. Hierarchical attention network to manage processing resources of CPSs. Extended Abstract at SelPhys (Self-aware Cyber-Physical Systems) Workshop at the Cyber-Physical Systems Week in Pittsburgh, USA. http://ati.ttu.ee/~kalle/SelPhyS_2017_Extended_abstract_KTammemae.pdf, 2017.
[3] Gina Sprint and Diane J. Cook. Using smart homes to detect and analyze health events. Computer, pages 29–37, November 2016.
[4] M. Kerner, K. Tammemäe, "Hierarchical Temporal Memory implementation on FPGA using LFSR based spatial pooler address space generator", DDECS 2017, Dresden.
[5] Madis Kerner, Master's Degree, 2017, (sup) Kalle Tammemäe, Hierarchical Temporal Memory Based Predictive Model and Anomaly Detection Component on FPGA, Tallinn University of Technology School of Information Technologies, Department of Computer Systems.
[6] M. I. Posner and M. K. Rothbart, "Research on attention networks as a model for the integration of psychological science," Annual Review of Neuroscience, vol. 58, pp. 1–23, December 2007.
[7] J. S. Preden, K. Tammemäe, A. Jantsch, M. Leier, A. Riid, and E. Calis, "The benefits of self-awareness and attention in fog and mist computing," Computer, pp. 37–45, July 2015.

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