iEnergy – Sisteme mecatronice pentru utilizarea eficientă a energiei

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Summary

- Objectives of the project
- Realization plan
- Project implementation
- Results
- Next research possibilities

Objectives of the project

- Global objectives:
  - Realization of mechatronic systems for energy efficiency
  - Horizon 2020 proposals
  - Application of new methods, i.e. compressed sensing
  - Collaboration between TUCN departments (Collaboration between Dept. of Mechatronics and Machine Dynamics and Dept. of Automation)
  - Research stages at international companies.

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Challenges - energy consumption is a key issue

Wireless sensor networks (WSNs) are critically resource constrained by limited power supply, memory, processing performance and communication bandwidth.

Due to their limited power supply, energy consumption is a key issue in the design of protocols and algorithms for WSNs.

Energy efficiency is necessary in every level of WSN operations (e.g., sensing, computing, switching, transmission).

In the conventional view, energy consumption in WSNs is dominated by radio communications. But the energy consumption of radio communication mainly depends on the number of bits of data to be transmitted within the network.

In most cases, computational energy cost is insignificant compared to communication cost. For instance, the energy cost of transmitting one bit is typically around 500–1,000 times greater than that of a single 32-bit computation.

Challenges

Therefore, using compression to reduce the number of bits to be transmitted has the potential to drastically reduce communication energy costs and increase network lifetime. Thus, researchers have investigated optimal algorithms for the compression of sensed data, communication and sensing in WSNs.

Most existing data-driven energy management and conservation approaches for WSNs target reduction in communications energy at the cost of increased computational energy (e.g. computing 32-bit is 500-1000 smaller than 1 bit transmision).

In principle, most compression techniques work on reducing the number of bits needed to represent the sensed data, not on the reducing the amount of sensed data; hence, they are unable to utilize sensing energy costs efficiently in WSNs.

Importantly, in most cases, these approaches assume that sensing operations consume significantly less energy than radio transmission and reception.

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Operational Energy Costs in WSNs

In fact, the energy cost of sensing is not always insignificant, especially when using power hungry sensors, for example, gas sensors.

Compressed sensing (CS) provides an alternative to Shannon/Nyquist sampling when the signal under consideration is known to be sparse or compressible.

In WSN applications, the energy used by a node consists of the energy consumed by computing, receiving, transmitting, listening for messages on the radio channel, sampling data and sleeping.

The switching of state, especially in the radio, can also cause significant energy consumption.

Sensing Energy Cost

Due to the wide diversity of sensors, the power consumption of sensors varies greatly. For passive sensors, such as passive light or temperature sensors, power consumption is negligible in comparison to other devices on a wireless sensor node. On the other hand, for active sensors, such as sonar, soil and gas sensors, power consumption can be significant [RAZ2014].

$$E_{sm} = V_{dc} * I_i * T_i$$

Table 1. Sensing energy of the sensors.

Sensor Type	Representative Sensors	$T_s(s)$	$T_r(s)$	$E_{sm}(mJ)$
Acceleration	MMA7260Q [52]	0.001	0.002	0.0048
Pressure	2200/2600 Series [53]	NA	0.0005	0.0225
Light	ISL29002 [54]	NA	0.11	0.123
Proximity	CP18 [55]	0.1	0.001	48
Humidity	SHT1X [56]	0.011	8	72
Temperature	SHT1X [56]	0.011	5–30	270
Level	LUC-M10 [57]	NA	2	1,660
Gas(VOC)	MiCS-5521 [10]	30	30	4,800
Flow Control	FCS-GL1/2A4-AP8X-H1141 [58]	2	12	17,500
Gas (CO_2)	GE/Telaire 6004 [9]	120–600	120	225,000

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Computational Energy Cost

The computational energy cost (E_{comp}) of sensor nodes is a key constituent of the overall operational energy costs in WSNs.

$$E_{comp} = V_{dc} * I_{mcu-active} * T_{mcu-active} + V_{dc} * I_{mcu-sleep} * T_{mcu-sleep}$$

Communication Energy Cost

The communication energy cost, E_{comm}, is conventionally the most important constituent of the operational costs in WSNs. The constituents of E_{comm} are listening, transmission, reception, sleeping and switching energy [RAZ2014].

CC2420-Texas Instruments-transceiver designed for low power and low voltage wireless application

Components of E_{comm}	**CC2420 [61]**	**CC1000 [62]**	**AT86RF230 [63]**	**TDA5250 [64]**
$E_{tx}(mJ)$	5.97	52.97	5.13	18.83
$E_{rx}(mJ)$	6.38	19.62	4.83	97.3
$E_{listen}(mJ)$	30.13	13.83	22.12	85.7
$E_{slp}(mJ)$	1.077	1.078	6.47	0.0054
$E_{sw}(mJ)$	136.54	194.4	172.73	669.6
$E_{comm}(mJ)$	180.10	281.87	211.29	871.45

Energy sampling

Table 3. Comparison of E_{comm} with E_{sm} and E_{comp}.

Sensors	TelosB		Mica2		Imote2	
	E_{sm}	E_{comp}	E_{sm}	E_{comp}	E_{sm}	E_{comp}
MMA-7260Q	0.0000268	0.044	0.000017	0.096	0.0000268	4.01
2200/2600 Series	0.00013	0.044	0.000079	0.096	0.00013	4.01
ISL29002	0.00068	0.047	0.00044	0.106	0.00068	4.13
CP18	0.267	0.047	0.17	0.105	0.267	4.12
SHT1X (H)	0.4	0.043	0.255	0.77	0.4	12.8
SHT1X (T)	1.5	0.94	0.957	2.65	1.5	37
LUC-M10	9.22	0.104	5.89	0.266	9.22	6.2
MiCS-5521	26.98	1.84	17.242	5.2	26.98	69.9
FCS-GL1/2A4-AP8X-H1141	97.2	0.46	62.1	1.28	97.2	19.4
GE /Telaire 6004	1,249.25	9.03	798.2	25.64	1,249.25	333.8

It is obvious that sampling energy is not always insignificant, especially in the case of power hungry sensors, such as gas, flow control, level sensor, etc. For instance, in the case of the accelerometer MMA7260Q, Esm is only 0.0000268 times Ecomm (in TelosB/Imote2), but it becomes 1,249.25 times Ecomm in the CO_2 sensor, GE/Telaire 6004.

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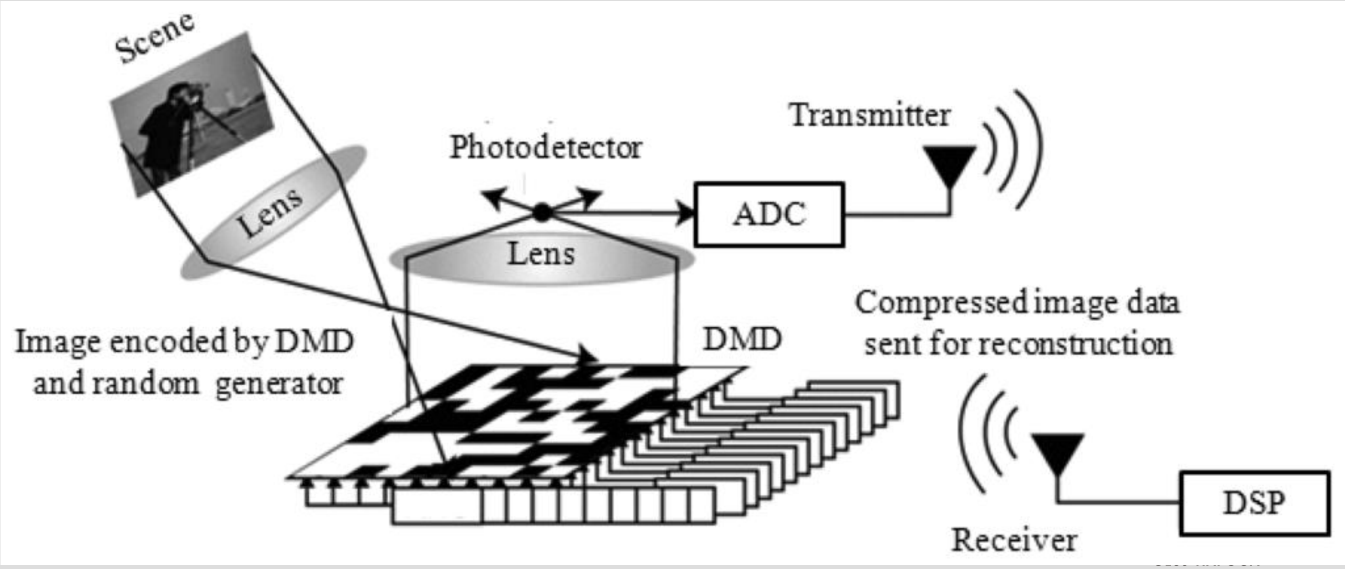
Compressed sensing

Concept of compressed sensing

Compressed sensing is a new paradigm for signal/image/function acquisition.

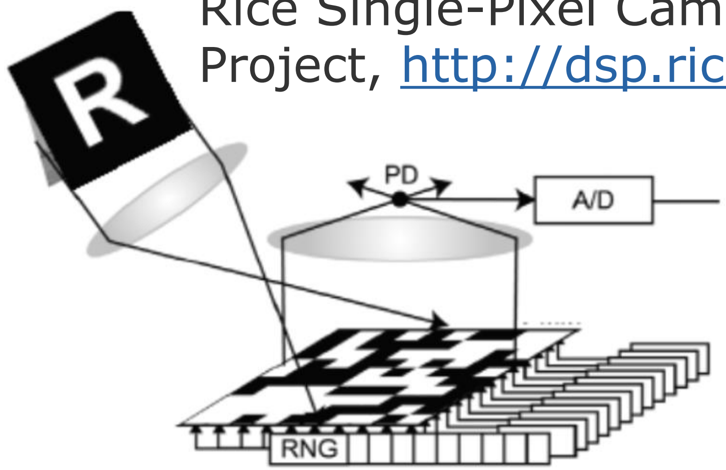
COMPRESSED SENSING is a signal processing technique for efficiently acquiring and reconstructing a signal, by finding solutions to underdetermined linear systems.

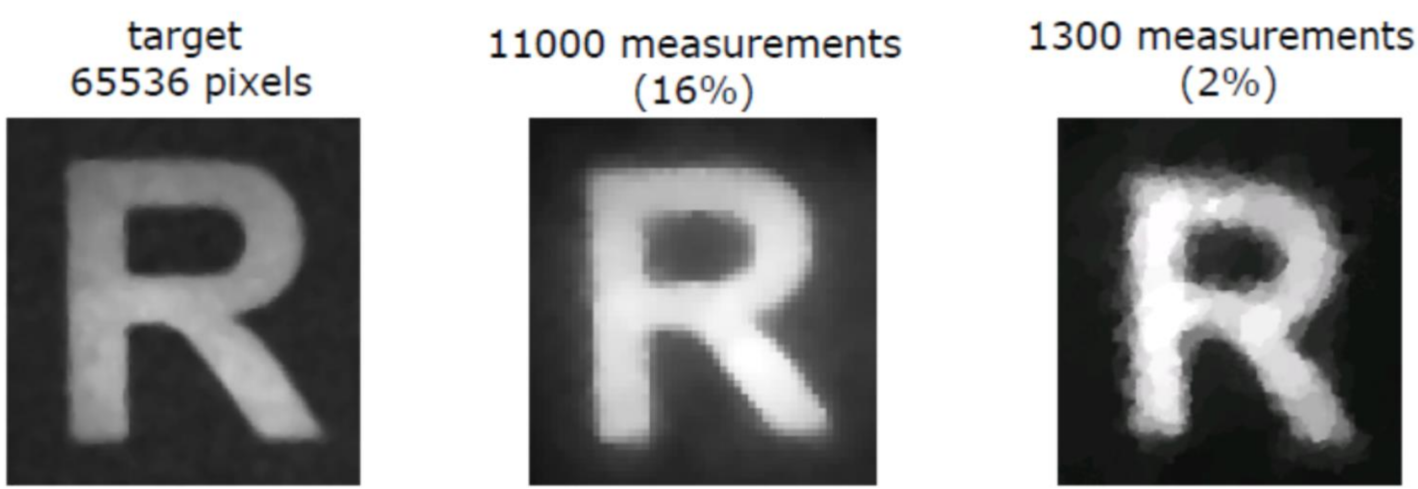
Is based on a sampling theory that uses compressibility without relying on any specific prior knowledge or assumption on signals.



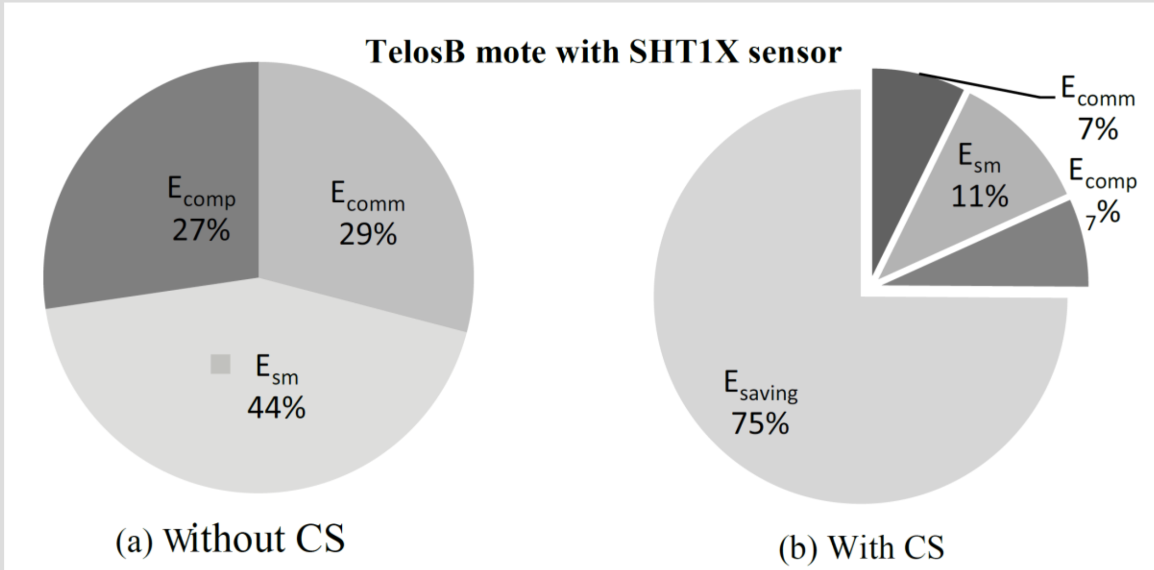
Example CS

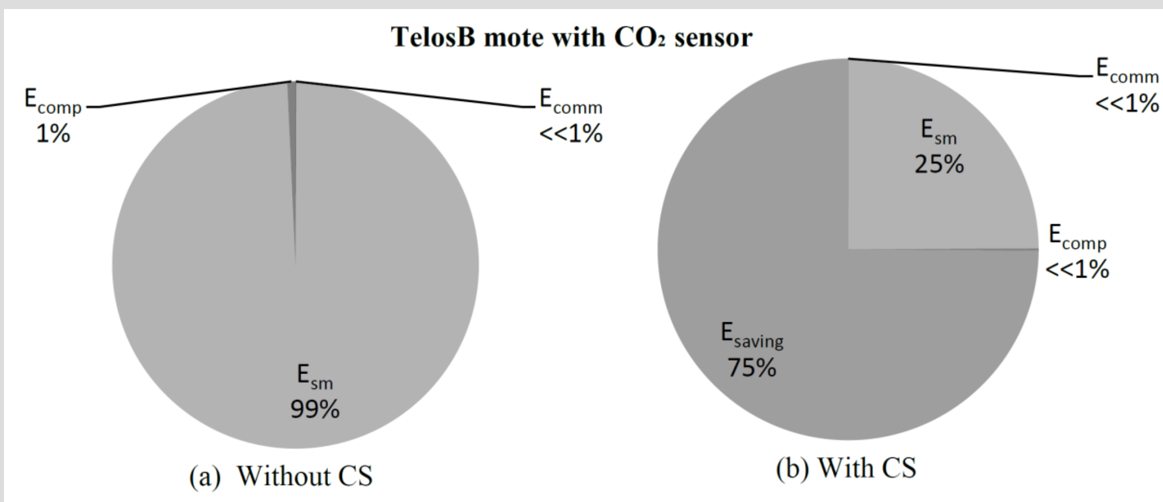
Rice Single-Pixel Camera Project, http://dsp.rice.edu/cscamera





Energy savings by using CS





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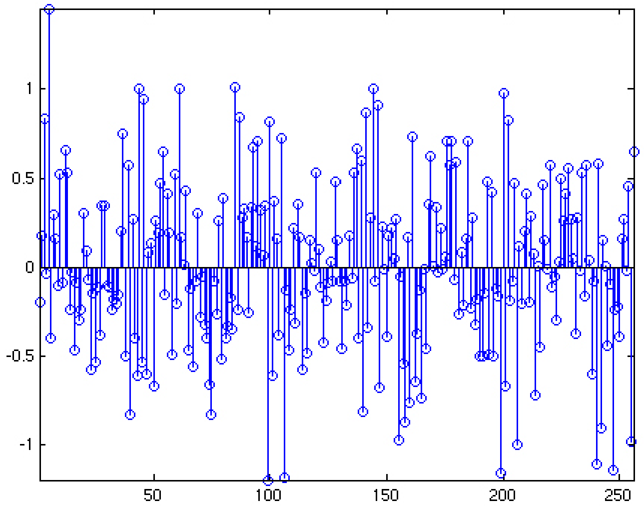
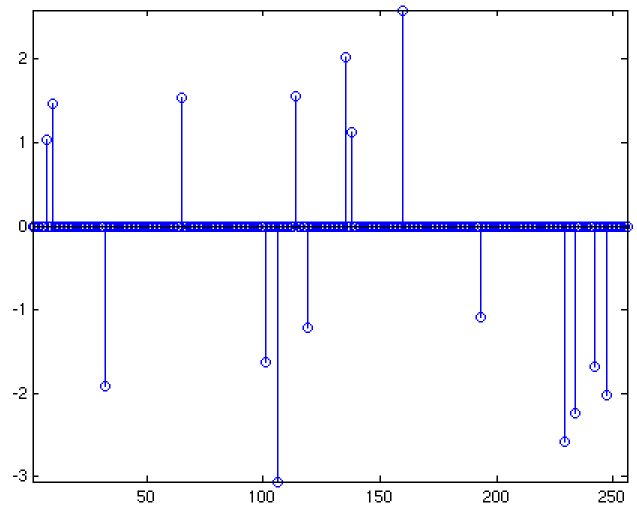
Example. 1D Implementation in L1Magic

Step 1: The original signal and its Fourier Transform.



Original Signal (N = 256)



Spectrum

The central idea in compressive sampling is that the number of samples we need to capture a signal depends primarily on its structural content, rather than its bandwidth.

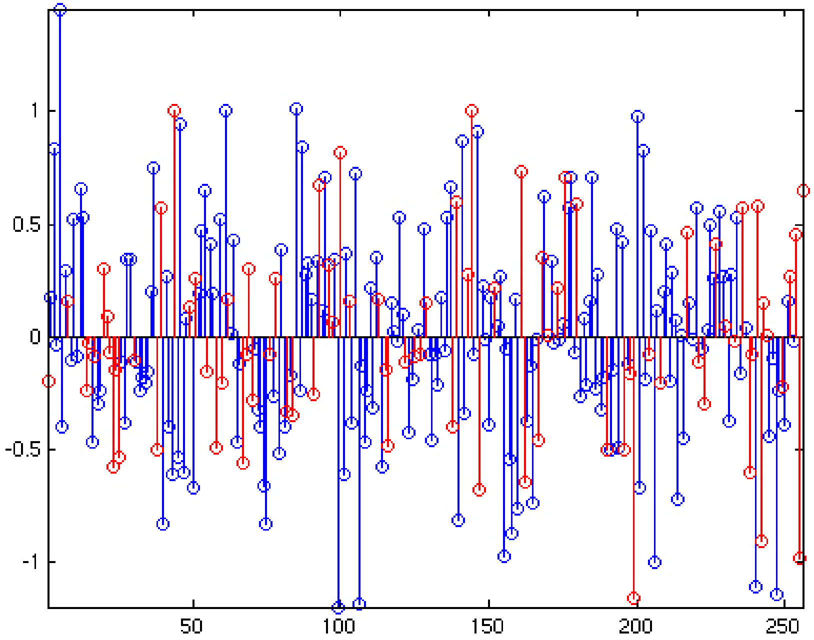
As a concrete example, suppose that **f is a discrete signal (of length 256)** composed of 16 complex sinusoids of whose frequencies, phases, and amplitudes are unknown. As such, the discrete Fourier transform (DFT) of f has 16 nonzero components (illustrated above).

Reference
http://users.ece.gatech.edu/~justin/l1magic/examples.html

Implementation in L1Magic

How many time-domain samples do we need to capture f? As there are no restriction on the frequencies in f, it is not at all bandlimited; any of the 256 components of the DFT can be nonzero. The Shannon/Nyquist theory then says that to recover this signal (via linear "sinc'' interpolation), we will need to have all 256 samples in the time domain.

Step 2: The subsampled signal



Red Entries (80 samples) are observed.

Blue Entries (176 samples) must be recovered.

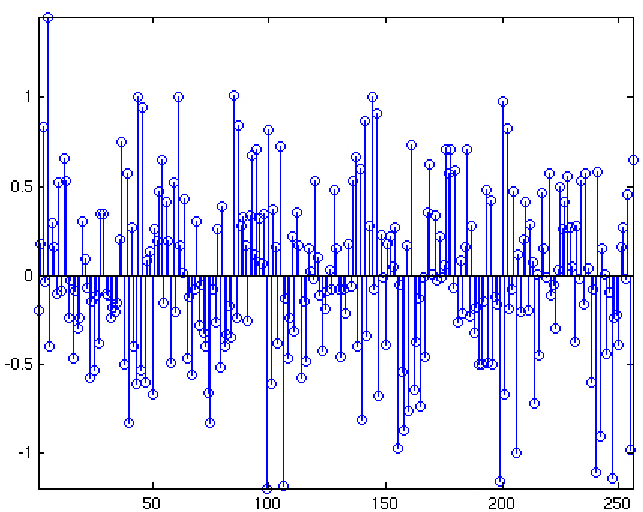
That means we observe only 30% of the original signal.

Reference
http://users.ece.gatech.edu/~justin/l1magic/examples.html

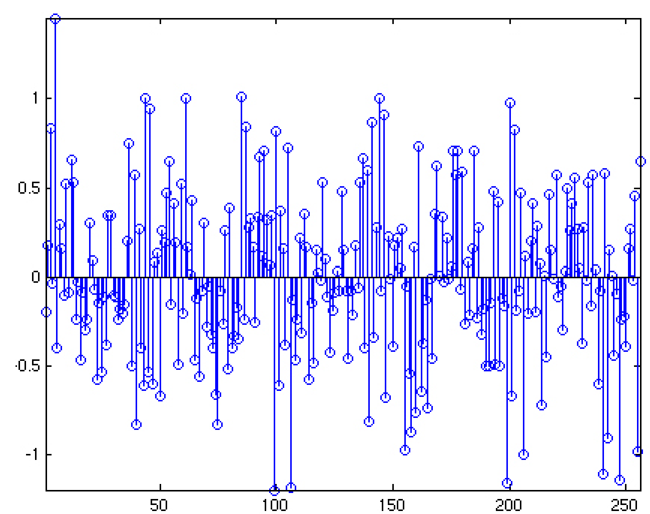
Implementation in L1Magic

Given these 80 observed samples, the set of length-256 signals that have samples that match our observations is an affine subspace of dimension 256-80=176. From the candidate signals in this set, we choose the one whose DFT has minimum L1 norm; that is, the sum of the magnitudes of the Fourier transform is the smallest. In doing this, we are able to recover the signal exactly!

Step 3: Exact Recovery of the Signal.



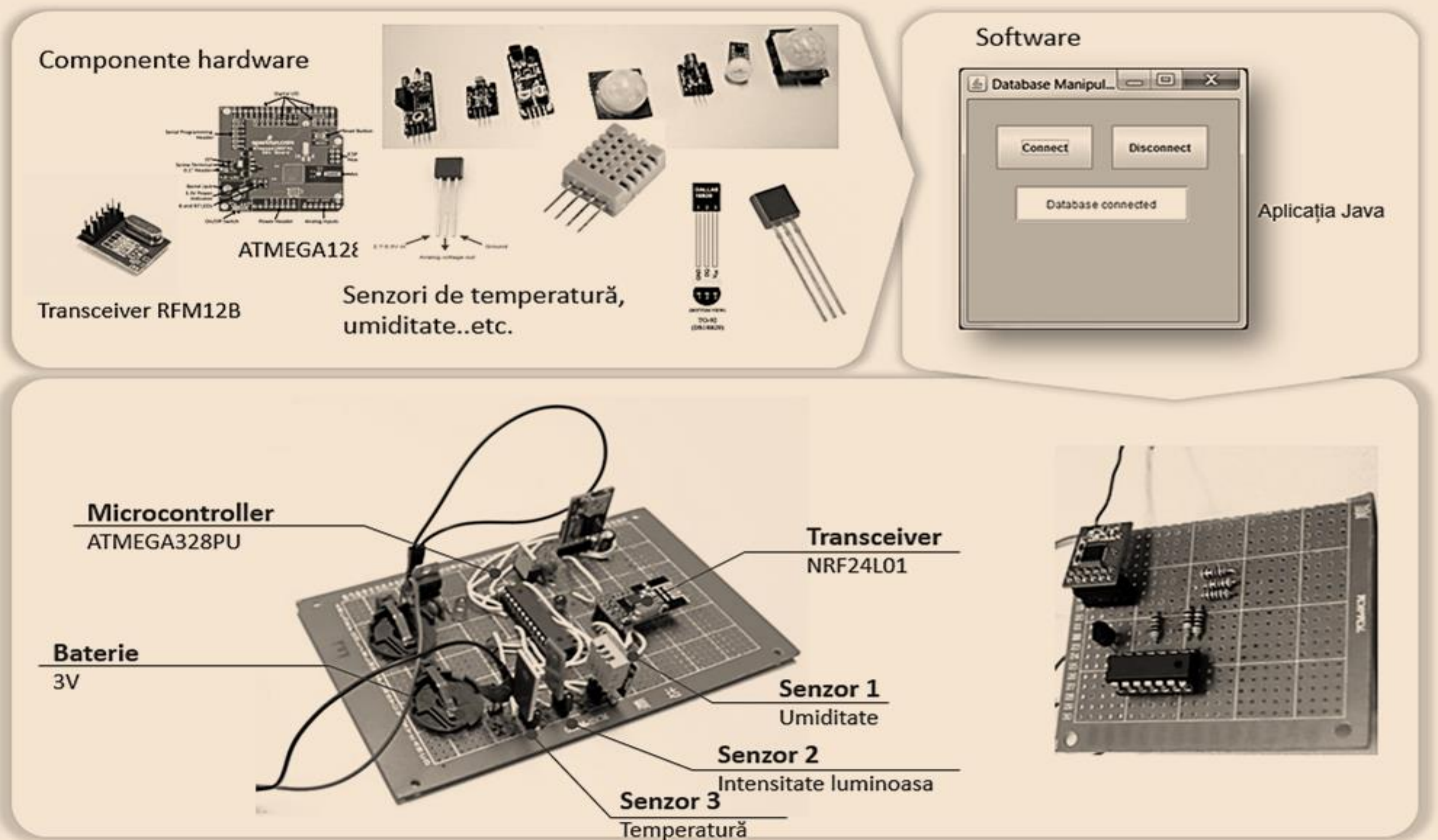
Original Signal (N = 256)



Reconstruction (N = 256)

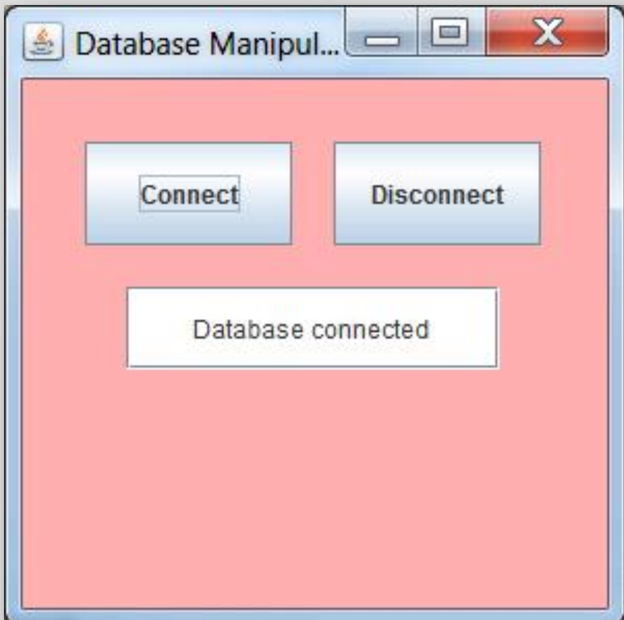
Reference
http://users.ece.gatech.edu/~justin/l1magic/examples.html

Realized wireless sensor



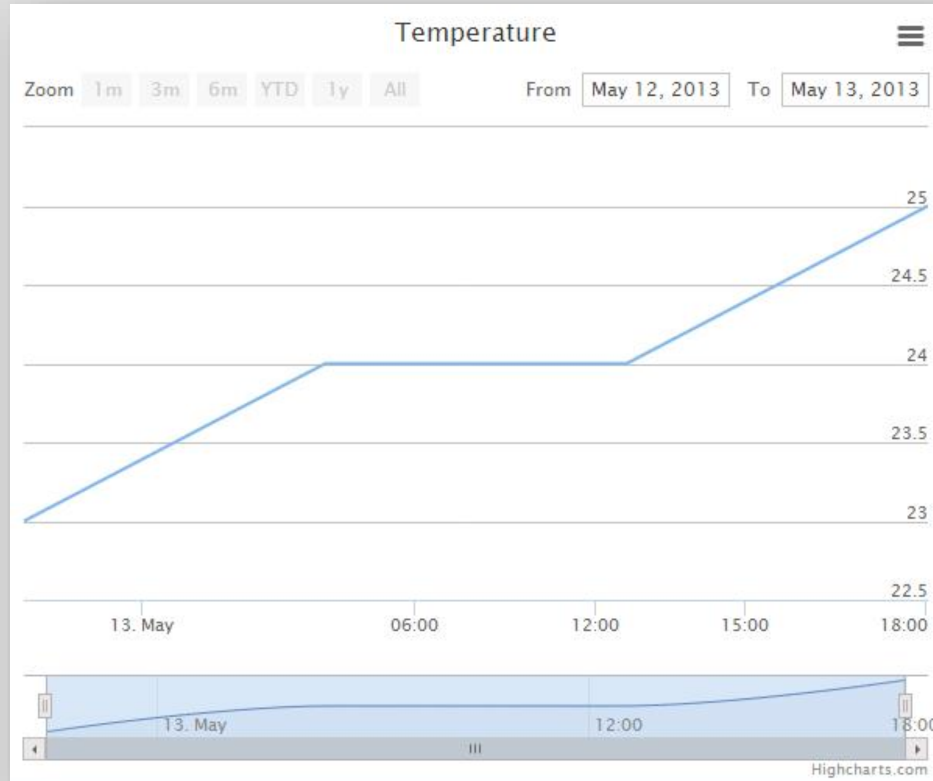
Platforma Software

-Java- -Interfața Php, Javascript-



Rol:

- Conectare la baza de date
- Citirea de date primite pe serial
- Salvarea datelor în sistem



- Afișare Date Senzori
- Interfața pentru controlul actuatorilor

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Collaboration with the company Hildebrand, UK

Courtesy of Hildebrand

- Research stage (3 researchers – 2014)
- Tests done with the Energyhive hub (The Energyhive hub delivers a real-time view of home energy consumption 24/7 through a web browser)
- 2 visits in 2014

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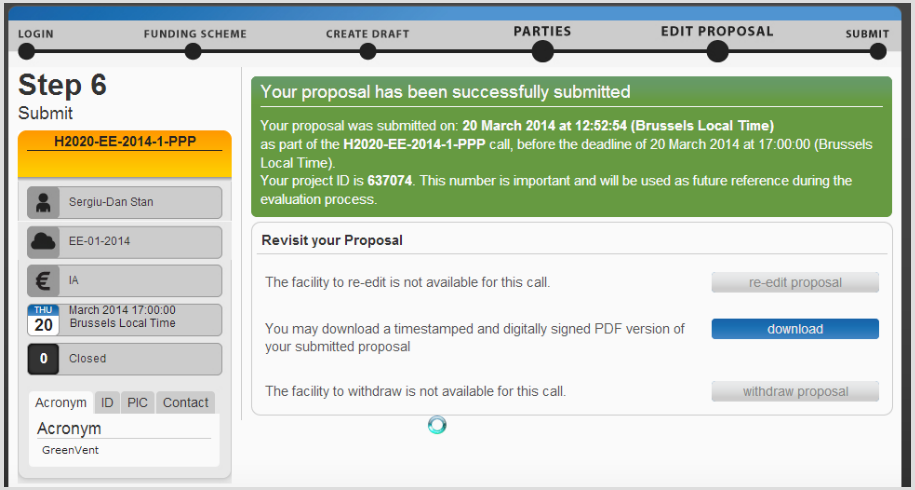
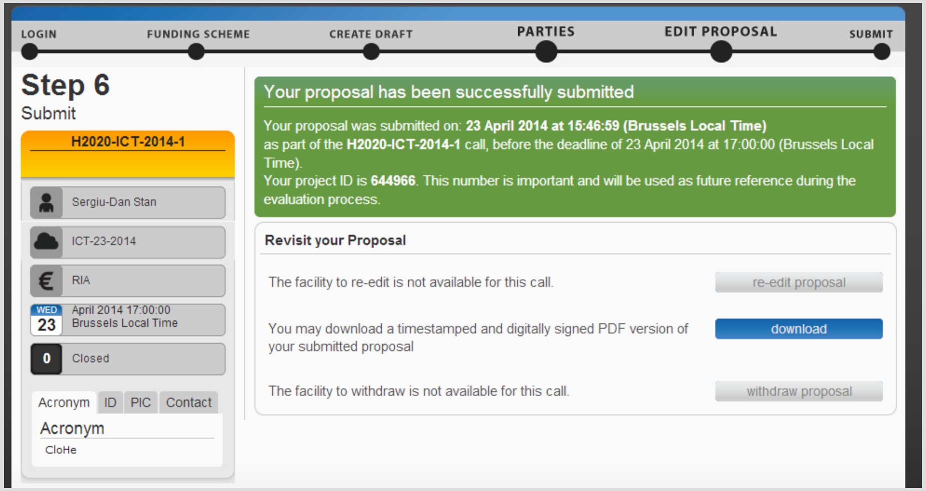
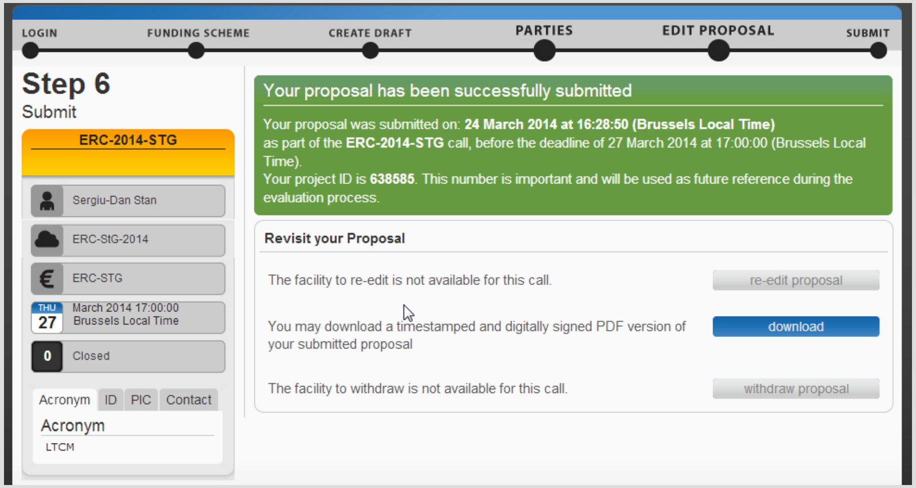
Horizon2020 proposals

GreenVent – H2020-EE-2014-1-PPP



CloHe – H2020-ICT-2014-1





LTCM – ERC-2014-STG

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Results

- 1 participation to an international conference
  - IEEE International Conference on Automation, Quality and Testing, Robotics AQTR, 22-24 May, Cluj-Napoca, Romania (**BDI**)
- 2 research mobilities:
  - At company Hildebrand Technology Ltd., London, United Kingdom, July 2014
- 1 BSC thesis, Department of Mechatronics and Machine Dynamics, July 2014.
- 3 project proposals within Horizon2020 program
- Collaboration with the company Hildebrand, United Kingdom for the energy monitoring hub and smart platform.

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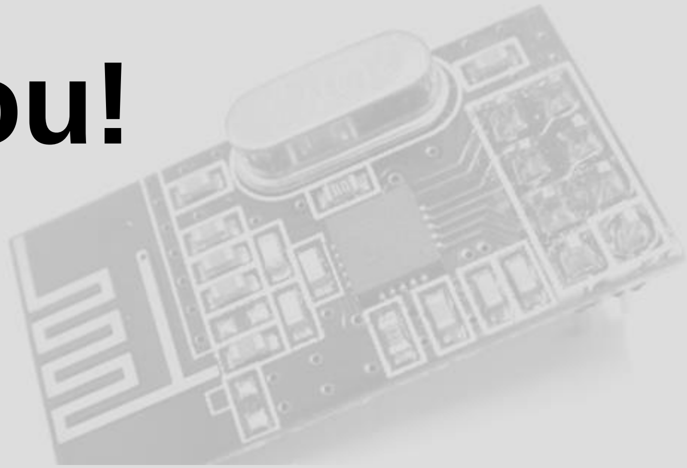
Next steps

- Collaboration with the company Hildebrand, United Kingdom
- Horizon2020 proposals
- 2 ISI articles

Thank you!



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