Signal Processing in Biohybrid System

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Commonly accepted definitions in signal processing

❖ Signal

- ✓ physical manifestation of information about the behavior or attributes of some phenomenon that appears in many different physical, symbolic, or abstract formats

❖ Signal processing

- ✓ enabling technology that encompasses the theory, algorithms, applications, and implementations of generation, transformation, interpretation and transferring information contained in signals

Commonly accepted definitions in signal processing

Are you aware of any other forms of signal processing?

Signal processing by biological entities

The main issues addressed in this presentation

- **How can we use benefits of biological signal processing?**
- **What are signal processing challenges in biohybrid system design?**

Structure of the presentation

- Introduction to biomimetic and biohybrid systems
- Cognitive biosensors
- Honeybee Activity Monitoring in a Biohybrid System for Explosive Detection
- Conclusion

Biomimetic and biohybrid systems

❖Biomimetic

- technology inspired by the processes and behavior of biological systems

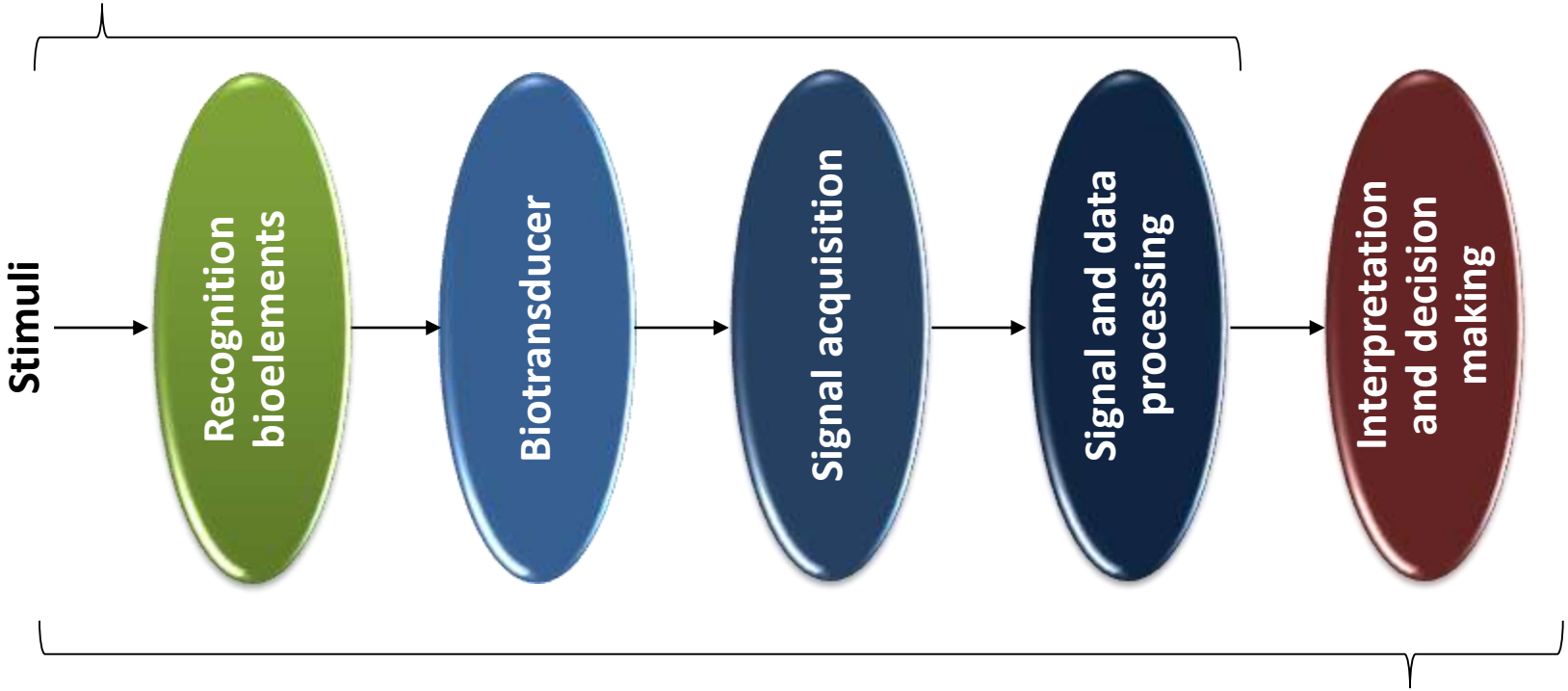
❖Biohybrid system

- form of bio-artificial entity, as a combination of biological and artificial systems with interfaces in one or both directions
- collect and interpret bio-signals that are not even available to the human in conscious cognition

- **Symbiotic biohybrid systems**
  - biological organisms and artificial components interact closely to ensure synergy and prosperity for both
- **Self-organized biohybrid systems**
  - biohybrid systems with the ability to learn, adapt, develop and self-organize

Cognitive biosensors

❖Biosensors



❖Cognitive biosensors

Cognitive biosensors

➢Recognition bioelements

- biological or biologically derived units capable to sense a specific stimulus

- isolated from living systems, or synthesized in the laboratory or farming
- molecular elements (receptors, enzymes, antibodies, nucleic acids, ...)
- whole cell biosensors
- complex species, for example insects and other animals

Cognitive biosensors

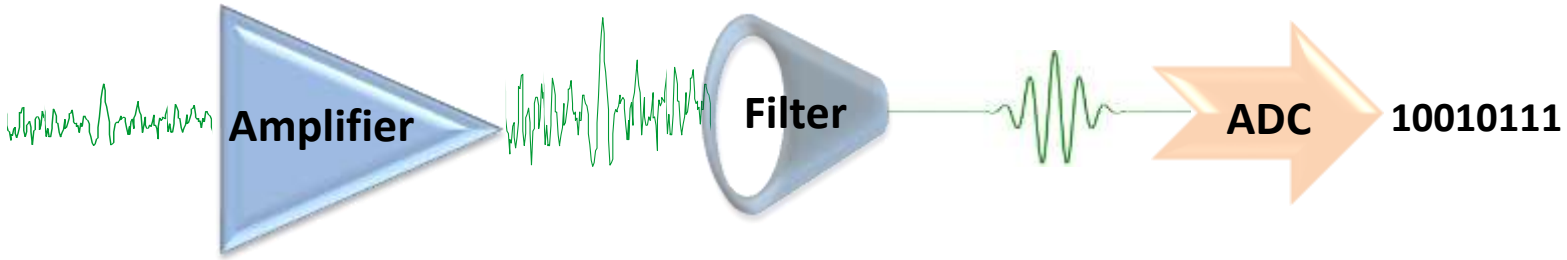
➢Biotransducers

- convert physical quantities to electrical signal

- electrochemical (amperometric, potentiometric)
- electrical (impedimetric, ion-sensitive)
- optical (fluorescence, iluminiscence)
- piezoelectric (mass detection methods)
- species behaviors to electrical signals in forms of audio, image and video

Cognitive biosensors

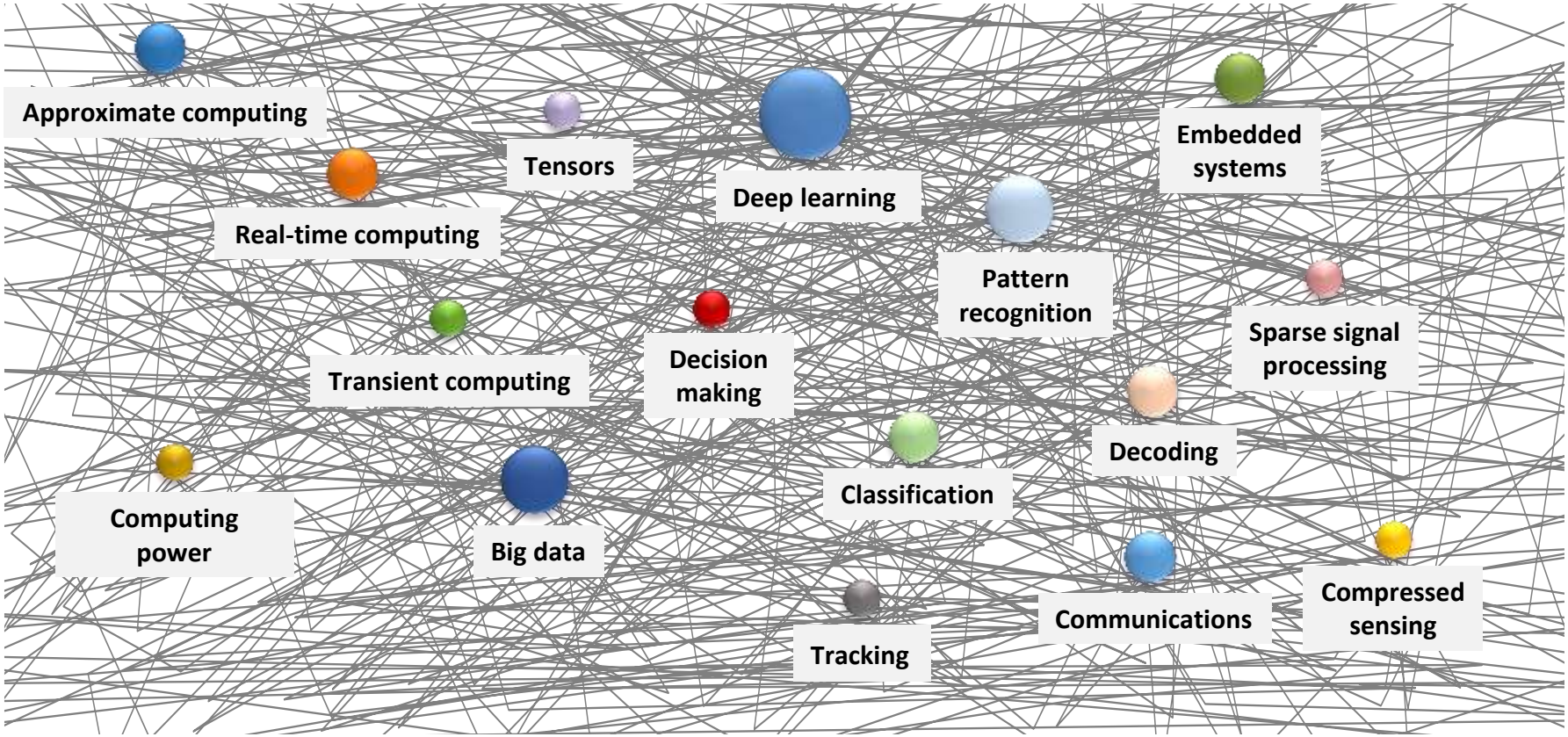
➢Signal acquisition



- signal conditioning in analog domain, amplification (dynamic range of biological signals)
- signal prefiltering (low signal to noise ratio, noises and interfering inputs in biological processes, response and recovery time)
- sampling and quantization, coding (response time and resolution, nonlinear characteristics)
- precision and accuracy depend on electronic components as well as on the nature of biological process (nonlinear characteristics, hysteresis...)
- nonuniform distribution of biological components in space and time

Cognitive biosensors

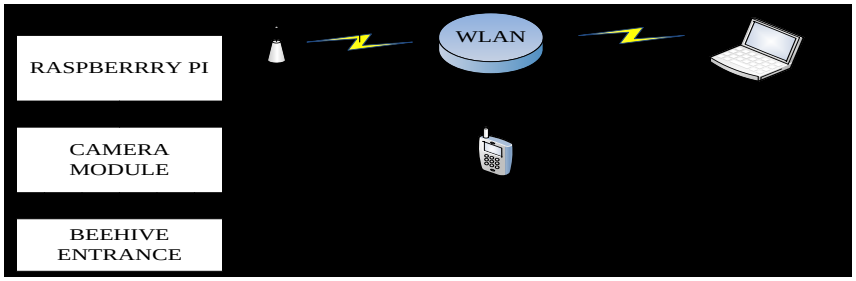
➢Signal and data processing

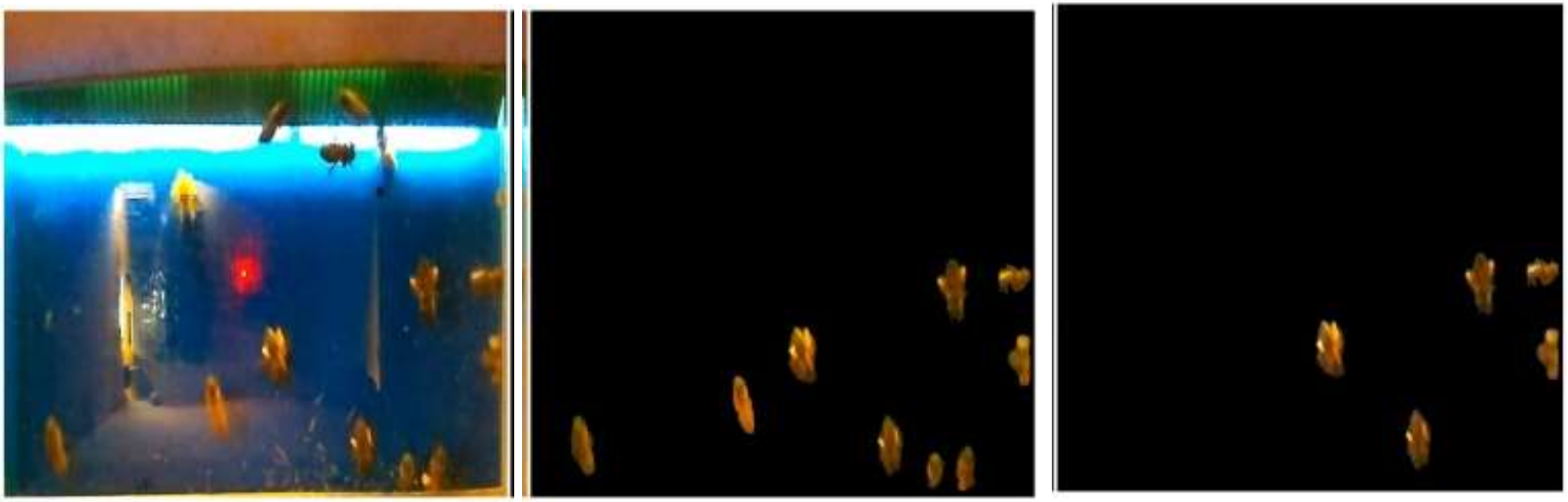


Cognitive biosensors with honeybees

- **Pollination monitoring**
- **Explosive detection**

Cognitive biosensors with honeybees for pollination monitoring





Cognitive biosensors with honeybees for explosive detection

The results of the project 

'Biological Method (Bees) for Explosive Detection'

Cognitive biosensors with honeybees for explosive detection

Bees conditioning

Cognitive biosensors with honeybees for explosive detection

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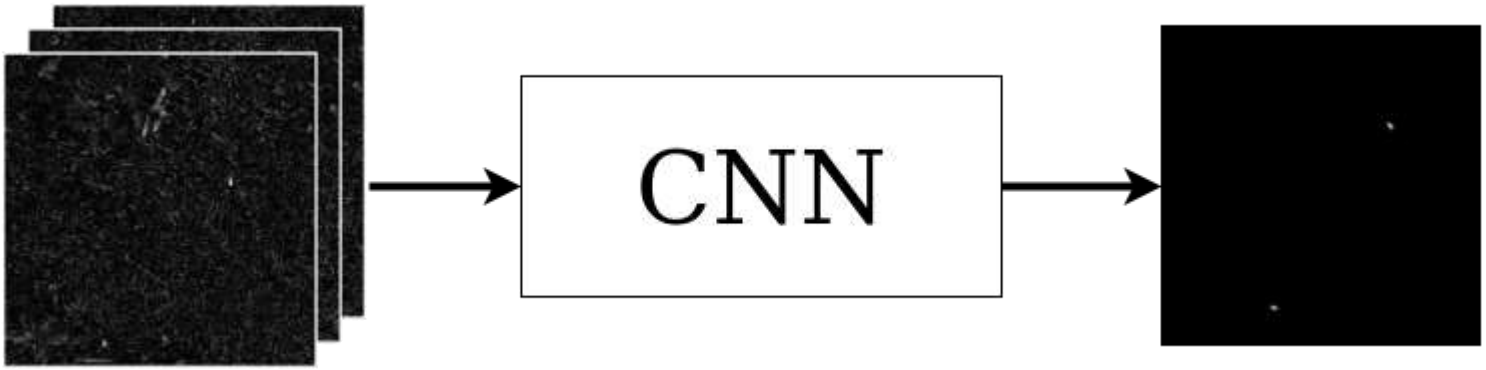
Cognitive biosensors with honeybees for explosive detection



Detection using CNN

Cognitive biosensors with honeybees for explosive detection

How to get data?

- **To train a CNN in supervised manner we need a lot of labeled data.**
- **Manual labeling of bees is very hard.**
- **Solution: we create videos with synthetic bees.**

Cognitive biosensors with honeybees for explosive detection

Bees modeling

- **Bees are modeled using gaussians with different colors, transparency and size.**
- **Random movement is modeled with the constraints regarding:**
  - **moving distance,**
  - **moving direction.**
- **Bees are elongated in the direction of movement.**

Cognitive biosensors with honeybees for explosive detection

Cognitive biosensors with honeybees for explosive detection

Signal Processing in Biohybrid System

Honeybee Activity Monitoring in a Biohybrid System for Explosive Detection

- **Electronic system for bees' activity monitoring**

Electronic system for bees' activity monitoring

Well-known restrictions in the use of bees are

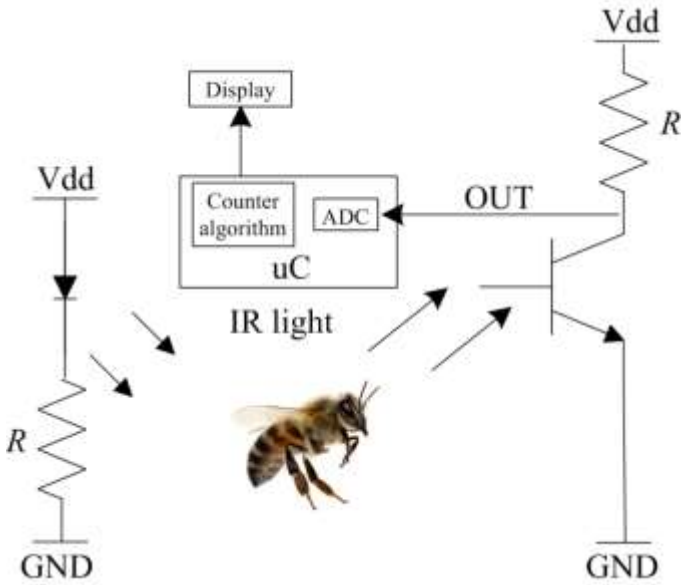
- low temperature
- rain
- wind

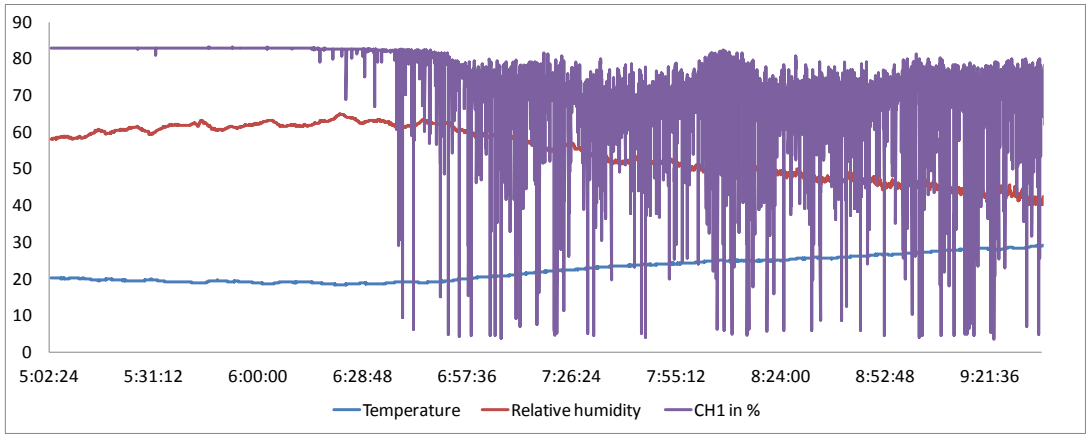
However, investigation of the influence of other environmental parameters is very important for understanding bee behavior in the field

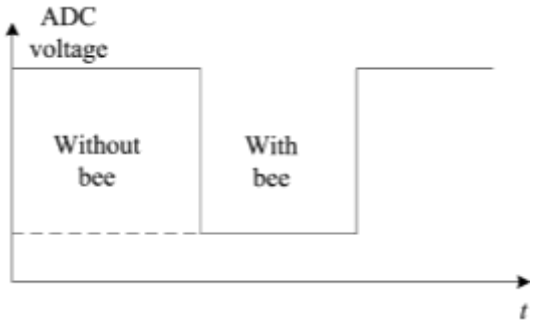
Our electronic system for bee activity monitoring should provide information about environmental parameters with a time and date stamp, along with detected activity of bees at the entrance and at the exit of the beehive.

Such information can be very useful in planning testing activities, as it can determine the optimal period of the day and environmental parameters in which bees are most active.

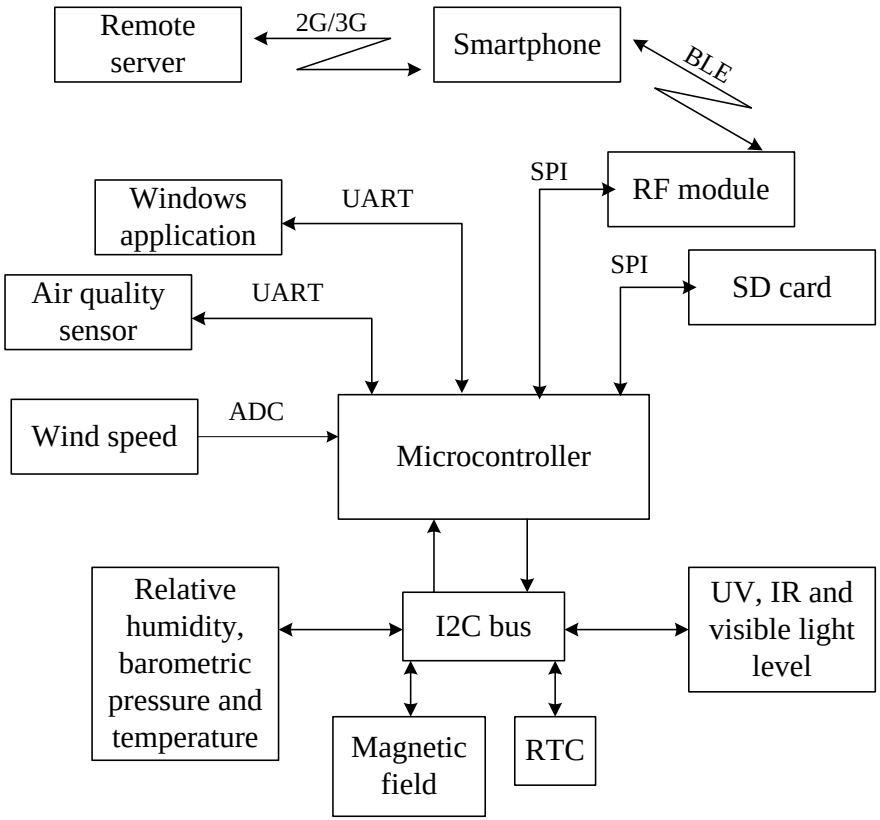
Electronic system for bees' activity monitoring







Electronic system for bees' activity monitoring



Conclusion

Synergy of recognition bioelements and artificial systems with cognitive signal processing algorithms, modeling of randomness mechanism and biological systems, communication with plants and animals and nanocommunication, and biohybrid systems with the ability to learn, develop and self-organize are emerging fields of research where system theory and signal processing play very important roles.

Beside classical signal processing algorithms, signal processing methods that include compressed sensing, sparse digital signal processing, big data, tensors, approximate computing, transient computing, and deep learning are encouraging and will likely lead to some progress. But for the greater progress in the area of biohybrid systems, methods that will go beyond classical theory and solutions are necessary.

Signal Processing in Biohybrid System

Thank you!

Questions ?

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