BoWI Executive Summary (2012-2016)

Introduction

The BoWI team aimed to apply a cross-layer approach combining techniques at different levels (antennas, radio channels, phy/mac protocols, dedicated hardware, distributed algorithms) to reach an ambitious objective of posture/gesture recognition in outdoor/indoor context with all day long wearable solution, based on a Wireless Body Sensor Network (WBSN). Considering expected energy harvesting capabilities we fixed an arbitrary objective of 100μW.

Organization and difficulties

The project was originally based on 4 thesis and 1 postdoc dedicated to usage and new applications. It was managed with three plenary meetings per year and innumerable small groups meetings on specific topics. A BoWI week was also organized in Brest in 2014. 3 PhDs are defended (Radio Channel & Antennas, Cooperative Communications, Algorithms & Architecture) but the PhD candidate working on recognition algorithms gave up prematurely and the work was so combined with the node architecture design. So we did not explore distributed algorithms as far as expected.
Then we had to recruit the designer (postdoc 12 months) at the very beginning of the project to work on possible future usages. It would be more efficient to have the designer at the end of the project to use and evaluate the prototype with real-life cases. Scientifically speaking we had to face some disappointing outcomes. As we have feared, it appeared that RSSI (received radio signal power) variations, with 2.4GHz narrow band radio links, are too important to get accurate distance estimation. However the redundant data set offers by all node pairs allows to identify postures. We have then used an UWB radio, from Decawave, that provides time of flight estimation but it is power greedy, it could be use with sparity when necessary but, as available lately with the second prototype, it was not possible to run enough experiments. This will be performed in the valorization phase. Finally, we also observed that cooperative communications with 2.4GHz narrow band radio can offer performance gains for distance larger than BAN (body-area network) size, which can be useful for BAN-environment communications.
Another important difficulty is the calibration of sensors and by extension the necessity to associate a generic initialization method so that non-expert users can follow a simple procedure before using the BoWI system for a given application domain.

Achievements and contributions

The BoWI project was first a fruitful environment for interdisciplinary research and discussions, the better understanding of interactions between all the project aspects, from sensor to posture identifications, was a real benefit for all members. We can highlight the following main results.

Algorithms

Researches on algorithms were conducted with a home-made simulator, with a strong interaction with other work on radio channels, antennas, case-studies and prototype design.
Contribution 1.1: "Combination of algorithms for posture recognition"
i) An NxN distance (RSSI) matrix, where N is the number of nodes, as a posture signature, ii) Data fusion with distributed PCA based on Magnetometers, Accelerometer and RSSI Matrix without the use of power greedy

gyrometers. Each node computes a part of the PCA vector and transmits a partial classification to a central node that finally decides (e.g. smartphone).

Contribution 1.2: "Gesture Recognition as a sequence of postures"

The method is based on an Extended Kalman Filter (EKF) producing Quaternions with data from Accelerometer, Magnetometer and Gyrometer, which is switched off during slow motions in order to save energy. A quaternion-based PCA can also be computed in a distributed way.

Radio

Antennas and radio channel are crucial parts of BoWI project which is comprised of low-power wireless sensor nodes operating in close proximity to human body, hence forming a WBSN. The contribution is focused around two main topics for WBSN applications, namely radio channel characterization and antenna design, as the two are closely related.

Contribution 2.1: "Radio channel characterization using ultra-miniaturized chip antennas"

Extensive measurement campaigns were undertaken on real human subjects in rich multipath environment using BoWI platform, which exploited chip antenna diversity. Significant improvement in ergodic channel capacity has been reported in this perspective. A robust fitting algorithm has also been developed which can detect accurately the best-fit channel model by generating a tight competition between seven benchmark distributions. Based on the proposed algorithm, first-order fading models have been derived for both on- and off-body channels using real-time measurements.

Contribution 2.2: "Antenna design and interaction with human body"

A compact, multimode antenna has been designed which offers pattern diversity at single frequency for both on- and off-body communications. This design circumvents the use of antenna arrays since space and form factor are crucial for wearable applications, meanwhile it offers a stable on-body performance. Furthermore, the interest of pattern and polarization diversities simultaneously has been studied for body-centric applications using the proposed diversity antenna. Significant improvements in link budget have been reported, which are corroborated by both full-wave simulations and real-time measurements.

Contribution 2.3: "Miniaturized chip antenna design and numerical channel simulator

For numerical channel studies, a miniaturized chip antenna was designed to approximate the radio performance of Zyggie prototype platform in simulation environment. A robust channel simulator was then developed using the chip antenna on tunable, realistic body morphologies with a number of intelligent enhancements to scale down the electrically extraordinary large problems to realize with limited computer resources. Finally, the application of the simulator has been demonstrated for interactive gesture recognition concept, revealing its advantage for BoWI.

Cooperative Communications

Radio power consumption is dominant in W(B)SN. The objective was to take advantage of node cooperation in order to enhance energy efficiency by means of space-time diversity in the context of the BoWI BAN. The main outcomes are related to the communications between the BAN and its close environment.

Contribution 3.1: "Efficient distributed precoding scheme"

For the communication between the BAN and a base station (BS) we propose a new approach, namely the distributed max-dmin precoding (DMP). Based on an amplify-and-forward or decode-and-forward relaying protocol, a virtual 2×2 max-dmin precoding is deployed over one source, one forwarding relay, both equipped with one antenna and the destination involving two antennas. Compared with conventional schemes such as distributed Alamouti, it brings substantial energy gains, of the order of the ten of microjoules, for medium distances (more than 15 meters).

Contribution 3.2: "Theoretical analysis and optimal power allocation at source and relay"

The performance of our distributed precoding was analytically derived for both the Amplify-and-Forward (AF) and Decode-and-Forward (DF) schemes. This theoretical analysis facilitates the performance evaluation and the power allocation, among the nodes and the protocol phases, in a large variety of scenarios. The derived upper bounds of the error probability for the DF transmission scheme, validated with Monte Carlo simulations, allow an efficient power allocation with a significant performance improvement, roughly 2.5 dB at BER equal to 10^{-2} for the DF scheme, compared to an equal power allocation.

Architecture

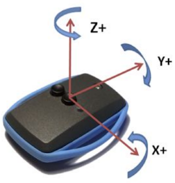
The objective was to increase local computation to reduce data communication volume and global power consumption. However, a microcontroller consumes orders of magnitude more than the energy budget target. So the challenge was the design of a low-power dedicated architecture to reach an extreme power efficiency.

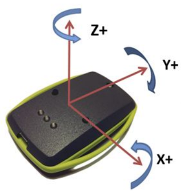
Contribution 4.1: Design of a hardware architecture that reaches the power consumption objective while executing a parameterizable EKF, which is the greediest part. It can also handle other modules for orientation only (degraded modes), partial PCA and motion detection. The power consumption with a 28nm FD-SOI technology is 40µW@50Hz (sample rate).

Contribution 4.2: An adaptive power management scheme selects the architecture and algorithm modes (w/wo gyroscope, w/wo EKF, sampling rate) according to the type of moves.

Prototype:

In parallel with theoretical aspects, we develop prototypes of BoWI nodes. The objective were i) the collection of data to experiment and validate algorithms and radio channel models and ii) the possibility to evaluate usage scenario. The first prototype (Zyggie v1) was available at the end of the first year and was used mainly for measurements. It was mainly composed of a microcontroller, IMU sensor module and 802.15.4 radio links. Zyggie v2 has been released in 2016, it was enhanced with ARM Cortex-M4 that allows to compute locally BoWI algorithms, a more efficient IMU and a UWB Decawave chip for distance measurements with ultra-wide band time-of-flight.



Besides, different software were developed (PC and mobile versions) to experiments algorithm and play usage scenarios in the domain of Functional Rehabilitation (sequences of predefined slow gestures) and Gaming (posture imitation).

One of the remarkable results that was made possible with Zyggie is the convergence between the radio simulation and the measurement. It means that we can expect generic model for RSSI matrix that can be combined with manufacturer data for sensors in order to provide a channel model to improve distance estimation using radio signals.

Valorization

BoWI is now ready for real-life experiments and we have a lot of opportunities for posture or gesture recognition. With Zyggie V2 we have a solution that allows for recording and classification of all day long in outdoor or indoor activities. Our platform is also a way to invent new types of applications in domains such as health, home automation, games and sport.

On a concrete level we have the following strong perspectives in the domain of healthcare:

- Functional rehabilitation and musculoskeletal disorders prevention: experiments with Kerpape Center and Rennes Hospital
- Factory for the future: work arduousness quantification which is perfectly adapted to BoWI since based on a codified set of postures.

The BoWI team is now looking for funding to go from prototype to real life experiment with partners already ready to collaborate.