BoWI Project

Body World Interaction

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Journées Ouest IRT / Labex CominLabs
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Outline

1. Project overview
2. Recent progresses
   - Usage
   - Radio
   - Algorithms
   - Architecture
   - Network
3. Perspectives
1- Overview: Labex Challenges

- Digital Environment for the Citizen + Energy Efficiency in ICT
- New **Wireless Body Area Network** for **Gesture / Posture** recognition
  - In- or out-door, everyday environment **without additional equipment**
  - Ultimate **low power**: no battery but energy harvesting
1- Overview: Technical Challenges

Cross-layer approach taking advantage of diversity and redundancy.

1. **Accurate short-range geolocalization** based on distributed multiple sensor fusion: IMU + Radio.
2. **Self-powered and self-adaptive computing platform**
3. **Channel propagation modeling and adaptive antennas**
4. **Dynamic protocols, cooperative communications and coding**
5. **New body-world interfaces exploiting the BoWI concept for digital citizens.**
1- Overview: Current GAP

• **VICON**
  - Camera set + Reflectors
  - Accurate
  - Equipped environment

• **Xsense MOVEN**
  - 9 DoF IMU (MTX) + Standard Embedded processor
  - Xbus / PC: BT connection
  - 17 MTX @350mW
  - 3 orders of magnitude over Energy Harvesting
1- Overview: Project organization

**Usage**
(Designer 12months, 2013)

- **Inertial Sensors**
- **Dynamic Cooperative Communication Protocol Wake-Up Radio**
- **Archi. HW/SW Self-adaptivity for Power Optimisation**
- **Channel Models + Antennas**
- **Geolocalisation based on multi-sensors and Distributed Algorithms**
- **New UWB?**
- **mm-Waves Front End**

**Short-Range Geolocation + Multi-Sensor**

- **Prototype (Engineer, 2013)**
- **Network Protocol-Coding**
- **HW/SW/COM Node Architecture**

**BoWI Research Scope**

**Post BoWI timeline**

**Available**

**Soon**

BAN (eg Zigbee or upcoming UWB 802.15.4a)
1- Overview: project strategy

**Prototype 2.4GHz**

**Algorithm**
- Bayesian Filtering
- Trialeration
- Classification

**Node Architecture**
- Reconfigurable
- Float => Fixed point

**Channel Modeling**
Antenna Design
2.4 => 60GHz

**Simulator (Matlab)**

**Usage**
- Case studies
- Capture

**Power Optimization**

**Protocols**
- Wake Up Radio

**Computation & Control Resources**

- Lab-STICC/CERV (Xsens/Moven)
- Univ. Sherbrook, CA (Optotrack)
- ENS/INRIA (Vicon)

**Raw data**

**Models**

**Constraints**

**Channel Modeling**

**Antenna Design**
2.4 => 60GHz

**Protocols**
- Wake Up Radio

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**Protocols**
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2- Recent progress
2.1- Usage
2.1- Usage: Combinatorial alphabet

- **Original Idea:** Propose the first standard combinatorial alphabet of gestures
  - Head, Arm, Back, Legs > 2000 postures
  - Testbench for BoWI
  - No specific meaning but thousands of combinations for various applications cases

e.g. Left and Right Arms: 16 possibilities
2.1- Usage / 1st Test Scenario: Imitation Game

- Technological demonstrator
- “Simon”-inspired Simple and Playful Game
- Popularize the alphabet
2.1- Usage / 1\textsuperscript{nd} prospective scenario

- Functional rehabilitation
- Remote monitoring
2.1- Usage / 2\textsuperscript{nd} prospective scenario

- Social Network
- Gestures = Communication
- Share Timed and localized emotions

Based on Schlosberg’s Emotion Organization
2.2- Radio
2.2- Radio Channel

1. 2.4GHz Zyggie Antenna Adaptation, ISM band, Johanson Chip
2. On-body channel measurements:
   - Instability
   - Ongoing: Phantom Based measures + Statistical Model (Wiserban project)
   - Diversity can offer advantages

13 cm \( \sim \lambda_o \) at 2.25GHz
2.2- Radio Channel

3. Inter-BAN Channel Modeling
   - **LOS**: Diversity interesting
   - **NLOS**: Poor, but acceptable channels

4. Short-term plan
   - POSER studio + CST integration: Radio channels for BoWI posture combinatorial alphabet
   - Scenario-based antenna design optimized for BoWI postures
     (Ground plane, Size, Radiation pattern, Polarization)

5. Long-term plan
   - Study of mm-waves channels (e.g. 60GHz)
2.3- Algorithms
2.3- Global Scheme

- **Data Fusion and Redundancy**

  Position:  \( P_i^{(t)}[] = F_1( M_i[], \{D_{ij}[], P_{j\neq i}[]\}, P_i^{(t-1)}[] ) \)
  
  Posture ID:  \( G_i[] = F_2( \{D_{ij}[], P_j[], G_j[]\} ) \)

- **Adaptation:**
  - **F_1, F_2**: **Algorithms**, Type of used inputs, Input data rate, #iterations ...
  - Choice / Use of **Hardware resources** done accordingly
  - **Depending on**: Accuracy constraints, Energy availability, Motion, Node ...

\[ \text{Central Manager (smartphone)} \]

\[ \text{BoWI node} \]

\[ \text{E} \]

\[ \text{IMU} \]

\[ D_{ij}[], P_j[], G_j[] \]

\[ n_i \]

\[ M_i[] \]
2.3- Architecture Schematic

- Minimize Communications
- Self-adaptation
- Dedicated Node architecture
2.3- Simulator

Sensors

 Calibration Filter

Acc Gyr Mag

Orientation

Speed Position (x,y,z)

Position

Classif1

Node Algo

Radio Model

BVH

IMU synthesis

Position

Posture

Posture Comparison

Posture Comparison

Classif 2 Posture Decision

Motion capture

Noise model

Distance

Position

Posture

Distance

Posture projection

Smartphone

IMU synthesis

Calibration Filter

Kalman

LMS

IPE

Radio Model

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Radio Model
2-3 Iterative Position Estimation

- IPE Estimation based on distances:
  - Compute \([x_i, y_i, z_i]\) from all \(N_{j \neq i}[x_j, y_j, z_j, R_j]\)
  - Minimize cumulated distance function:

\[
\begin{align*}
  f(x, y, z) &= |(x - x_1) + (y - y_1) + (z - z_1) - r_1| \lambda_1 \\
&+ |(x - x_2) + (y - y_2) + (z - z_2) - r_2| \lambda_2 \\
&+ |(x - x_3) + (y - y_3) + (z - z_3) - r_3| \lambda_3 \\
&+ \ldots
\end{align*}
\]

- Optimization based on space dichotomy
  - 8 direction exploration
  - Dynamic step (/ \(2^k\))
  - Some distances can be fixed
2.3 IPE Simulation

- Average distance errors vs. $\sigma_{\text{Distance}}$ and $\sigma_{\text{Mems}}$ noise

<table>
<thead>
<tr>
<th>Accuracy stop criterion</th>
<th>$10^{-2}\text{m}$</th>
<th>$10^{-3}\text{m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nodes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27 nodes:</td>
<td></td>
<td></td>
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</table>
2-3 Prediction

- **Quaternelion** (orientation), angular & linear accelerations based on Kalman-like filters (EKF, UKF, Gradient, ...)
- Also used to improve **initial position** with prediction
2-3 Posture identification

- Example of Principal Component Analysis-based identification
  - Case of 86 Postures from a continuous Capueira movement
  - Highly correlated Postures: only 3 eigen vectors enough (correlation > 90%)
2-3 PCA-based identification

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2-3 Towards Posture Signature

- **Experiment on RSSI measurements with Zyggie**
  - 9 postures
  - 1min recording
  - Fixed positions
  - 3 environment (office, hall, park)

<table>
<thead>
<tr>
<th></th>
<th>Right arm up</th>
<th>Right arm middle</th>
<th>Right arm down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left arm up</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Left arm middle</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Left arm down</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>
2-3 Towards Posture Signature

- Experiment on RSSI measurements with Zyggie
  - Outdoor case
2-3 Towards Posture Signature

- Promising results: Redundancy to compensate radio inaccuracy
- Improve signature information content with other parameters:
  - High Order statistics
  - Gravity/Quaternion vectors
  - Prediction (inter-posture correlation)
- Ongoing work on different learning & classification methods:
  - Outlier elimination
  - Principal Component Analysis, Support Vector Machine, Neuron Networks
- Distributed algorithms
  - Parallel implementation on nodes
  - Node / Smartphone partitioning for communication minimization
2.4- Architecture
2-4 Towards Run-Time Fully Adaptive multi core Architecture

- Adaptive Hardware
  - Reconfigurable hardware specialized to Control/Compute/Store
  - Efficient dynamic reconfiguration
  - Fine-Grain Power Management
    - Power gating
    - Body Bias

Close to energy efficiency of fully specialized hardware but with much higher flexibility and hardware reuse.
2-4 Hardware / Algorithm adaptation

- Computation requirements / algorithm parameters
  - Algorithm choices => huge impact on computations (so power)
  - Node Level adaptation is mandatory
2-4 Hardware design projection

- Very first “ultimate bounds” estimations
  - 28nm FDSOI, 1nJ/bit, 7.5pJ/MAC32, no PCA, 48b messages
- **Case 1 (worst):** 17 nodes, EKF: 50Hz, IPE: 50Hz, M=1, Precision 1cm
- **Case 2:** 17 nodes, EKF: 50Hz, IPE: 25Hz, M=2, Precision 1cm
- **Case 3:** 17 nodes, EKF: 50Hz, IPE: 10Hz, M=3, Precision 1cm

<table>
<thead>
<tr>
<th>Ultimate Power Bounds</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computation + Memory:</td>
<td>5.9 µW</td>
<td>5.2 µW</td>
<td>4.9 µW</td>
</tr>
<tr>
<td>Radio</td>
<td>22 µW</td>
<td>7.7 µW</td>
<td>2.7 µW</td>
</tr>
</tbody>
</table>

- Notes:
  - Big impact of communication policy
  - MEMS not included: add 50µW without Gyrometer.
2.5- Network
2-5 MAC layer optimization

- Initial MAC protocol: IEEE802.15.4 (low power Zigbee)
  - Frame divided in timeslots
  - Each node listens in each time slot to get other node RSSI and send data to the manager
  - Balise: Synchro by the manager
  - SuperTrame: 123ms @ 8Hz
2-5 MAC layer optimization on Zyggie

- Improve MAC protocol: IEEE802.15.4 (low power Zigbee)
  - Separation of short RSSI and larger Data Frames
2-5 MAC layer optimization on Zyggie

- Improve MAC protocol: IEEE802.15.4 (low power Zigbee)
  - Separation of short RSSI and larger Data Frames

![Graph showing activation time vs. number of nodes for MAC1.1 and MAC2.1]
3- Conclusion & Perspectives
3- Conclusion

• Challenging project:
  - RSSI Inaccuracy
  - Ultra Low power architecture : < 200µW from (Energy Harvesting)
  - Distributed system with limited communications (Power impact)

• Opportunities
  - Adaptation (motion, correlation vs communication cost, etc..)
  - Redundancy
  - Operational Zyggie prototype for research (algorithms, communication, radio)
  - Multidisciplinary team
3- Perspectives

• **Short term**
  - Node Architecture Design
  - Classification method and Node/Smartphone partitioning
  - Channel modeling based on postures
  - MIMO (diversity, precoding, distributed)

• **Long term**
  - ASIC design
  - mm-waves front end
3- Perspectives

- Monitoring information
- Decision Application
- Management
- Postures/ Applications
- Compilation Synthesis
- Configuration Repositories