Wireless Body-Area Sensor Networks

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Aml

- **Ubiquitous Computing**
  Integration of “computers” in everyday objects (buildings, appliances, furniture, clothes, toys) - Weiser vision (1998)

- **Ubiquitous Communication**
  Enabling objects to communicate with each other by means of and ad-hoc & wireless networking

- **Intelligent (natural) User Interfaces**
  Enables the inhabitants of the AmI environment to control and interact with it in a natural (voice, gesture) and personalized (preferences, context) way!
Intelligent User Interfaces: Wearability vs Usability

- Interface = closed-loop (human in the loop)

- Sensing, Transduction, A/D conversion, Local Processing
- Input processing, Application-specific computation, Output rendering
- Wireless communication
- Output actuation

- ...more than just data collection: Real-time operation is key
  Millisecond loop delay is required for correct feedback operation, with human time constants
An evolutionary trajectory

Basic interaction: Biofeedback Wireless Wearable Systems

- **Bio-feedback** systems for balance and postural control
  - Equilibrium disorders caused by aging/diseases
  - Rehabilitation
  - Training
- **Typical loop**
  - Inertial sensors for body tracking
  - Audio feedback
  - Feedback control law implemented on a computer
- **Requirements**
  - Completely Wireless non-ambulatory usage
  - Wearable, low-cost, low-power
  - Modular, programmable and flexible
General Architecture of Bio-WWS

Actuation node
(audio feedback)

Gateway + PDA

Sensor nodes

Our choice: Data processing + biofeedback algorithm on PDA for a completely mobile solution

Hardware architecture

- Modular and stackable design
- Two possible setup for the hardware units

End-node

- Battery powered
- Sensor: Tri-axial MEMS digital accelerometer by STM
- Completely wireless
- Processing on board for:
  - Data acquisition
  - MAC protocol implementation
  - Processing on data (e.g. filtering, event generation)
Gateway

“Bridge” between end-nodes and general purpose system (PDA)

- Interface with the PDA:
  - Wireless: Bluetooth
  - Wired: e.g. USB, Ethernet, RS232

- Interface with the end-nodes:
  - Transceiver RFM TR1001
    - ASK/OOK modulation (up to 115.2kbps)
  - Proprietary MAC

Calibration

- Starting phase: the user stands still for a short time (~5sec)
- No bio-feedback, sway around the center of mass is registered
- Silent Zone and Limit Zone are extracted (1.5 and 10 of std dev)
PDA application

- Graphical User Interface
- Flexible and parameters tuning
- Profiling and Multi-user

Evaluation

- Mobility, Usability and Costs (still prototype!)

- Power Consumption
  - sampling frequency at 60Hz
  - 32kbps from node to gateway on OOK transmission at 868MHz, and at 230kbps from gateway to PDA (BT 2.4Ghz)

- System Performance
  - Sensing accuracy 1 mg
  - Distance in body <2m packet loss in practical case ~0

<table>
<thead>
<tr>
<th></th>
<th>Size and costs</th>
<th>Gateway</th>
<th>Node</th>
<th>PDA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29x29x18mm 35€</td>
<td>4x6x1,5cm 50€</td>
<td></td>
<td>7,5x1,9x11,9 cm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ON</th>
<th>IDLE</th>
<th>SLEEP</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Gateway</td>
<td>200 mW</td>
<td>25 mW</td>
<td>1,5mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node</td>
<td>45 mW</td>
<td>20 mW</td>
<td>10 μW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDA</td>
<td>350mW</td>
<td>/</td>
<td>/</td>
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Worst case: 8 hours lifetime
For a 20% duty cycle lifetime
GW=40h; node=38h;
Bottleneck PDA=12h (worst case BioWWS dedicated use)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Gateway-Node (m)</th>
<th>Packet Loss</th>
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<tbody>
<tr>
<td>0.5</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>18%</td>
<td></td>
</tr>
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</table>
Evaluation

- Validation test on users:
  - Healthy subjects stand with eyes closed on a foam-rubber surface

- Numerous other applications
  - Tracking static postures (e.g. fall detection)
  - Tracking dynamic postures (e.g. gait analysis)

BioWWS decreases the center of Pressure (CoP) excursion (measured with force platform based on strain-gage technology).

Evolution

- Streamline interface WBAN – Computing infrastructure
  - Proprietary protocol -> Bluetooth
    - Higher bandwidth
    - BT limitations (power, static network) not critical in this context

- Use WBAN nodes for feedback (actuators)
  - Aptics over WBAN
    - Force feedback poses severe power challenges
**Touch feedback**

- Realistic sensorial stimuli, within the power and form factor constrains of BWSNs

- Low cost;
- Non-invasive;
- Low Power;
- Small size and weight;
- Flexible;

**PIEZO ACTUATORS**

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**Tactile feedback implementation**

**PL140 (PiezoNanoPosition)**

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<tbody>
<tr>
<td>0.6-3.3</td>
<td>≤ 0.6</td>
<td>12x12</td>
<td>0.01-0.6</td>
<td>160</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Boost DC-DC CONVERTER**

The IC MAX1932 provides output voltate between 4.5 and 90V from power supply between 2.7 and 5.5V

Follow the white rabbit...
An evolutionary trajectory

- Basic interaction
  - Body-only

- Augmented interaction
  - Body & “Smart objects”

- Integrated interaction
  - Body & “Smart objects” & Environment

- Wear-ables
  & “hand-ables”

3dID: a Low-power, Low-cost Hand Motion Capture Device

- Low-end solutions: a multiplicity of gloves for HCI
  - Inertial, non-inertial, capturing fingers, wired…
  - CyberGlove, 5DT Data Glove, P5 Glove, etc.

- Our solution:
  - TRULY wireless
  - Wearable, low-cost, low-power, off-the-shelf components
  - Part of a WBAN
  - Easy add of new sensors (flexible and modular)
  - Programmable (microcontroller on board)
  - COMPLETE solution: software (SENIE)
Hardware architecture

- Modular and stackable design
- Two possible setup for the hardware units
  - **End-node**
    - Battery powered
    - Sensor equipped
    - Completely wireless
  - **Gateway (not needed for BT)**
    - Bridging between wireless node and a generic host (PC)
    - Wireless and wired interfaces to the host

Sensory

- **Finger flexion**
  - 5 Resistive bend sensors
    - A sensor for each finger.

- **Inertial Measurement Unit (IMU)**
  - 3-axial accelerometer
    - ST Electronics LIS3L02DQ
      - Translations in dynamic conditions
      - Rotations in static condition
  - 3 Piezo gyroscopes
    - Analog Devices ADXRS300
      - Rotations in dynamic conditions

- A multi-sensor node (a sensor cluster)
Software architecture

SeNIE
Sensor Network Integration Environment

Application layer
- Data processing

Calibration layer
- Data filtering
- Sensor related pre-processing

Driver layer
- Data loading
- Data forwarding/storage

Driver Layer

Chain of Responsibility
- **Runtime** generated
  - WSN independent
  - XML based
- **Finding** errors
  - Noise
  - De-synchronizations
  - Signal overlapping
- **Skipping** wrong packets
  - Chain reset
  - Error count
Calibration Layer

- Data filtering
  - Accelerometers intrinsic hardware noise and flickering
    - Butterworth filter
    - Kalman filter
  - Bend sensors value range is not constant, it is affected by ageing and could be temperature dependant
    - 3 threshold average filter
- Data conversion
  - Accelerometer could be used as inclinometers
    - Roll and Pitch converter
  - Simulation tools must transfer data to a fixed bit rate
    - Delay filter

Design evaluation

- Power
  - Very low power consumption
  - 14 hours of continuous usage at 50Hz acquisition rate with a 3,3 V/500 mAH battery working at 9600 bps
- Wireless Performance
  - Error < 10% at 5m
- Price
  - Total device cost is less than 150€

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>mW</th>
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<tbody>
<tr>
<td>Power Stabilizer</td>
<td>0.20</td>
</tr>
<tr>
<td>μC, Bend, Accelerometer</td>
<td>27.72</td>
</tr>
<tr>
<td>Transceiver</td>
<td>25.08</td>
</tr>
<tr>
<td>Gyroscopes</td>
<td>60.00</td>
</tr>
<tr>
<td>Total</td>
<td>113.00</td>
</tr>
</tbody>
</table>
**Smart objects**

- Wearables are objects we wear
  - Unobtrusive because we always wear things
- Humans used tools since pre-history, even before clothing
  - We want to make sensorized objects that are aware of how they are manipulated
  - Objects should not look “electronic”
  - No user manual: just “**try & see**”!

An evolutionary trajectory

- **Integrated interaction**
  - Body & “Smart objects” & Environment
- **Augmented interaction**
  - Body & “Smart objects”
- **Basic interaction**
  - Body-only

Follow the white rabbit.
Surveillance WSNs

Applications:
• Access surveillance
• Intrusion detection
• Lighting system control
• Machinery users safety
• Toys and AmI

Characteristics:
• Low-cost off-the-shelf component
• Extremely low-power
• Small
• The area of coverage controllable by a suitably shaped Fresnel lens

Augmenting High-End Video surveillance systems

• Help managing illumination or background changes (doors opened, objects moved)
• Occlusions: problems in direction changes
• Groups of people

Follow the white rabbit..
Why a wireless PIR network?

- Sensors output depend jointly on:
  - Distance
  - Speed
  - Temperature
  - Number of people or object size
  - Direction of movement

- Thus, aliasing may be significant: similar waveforms could be generated by different combinations of the above parameters.

**Solution:**
A network of PIR nodes

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More than just triggers...

Follow the white rabbit.

Great potential for enhanced motion tracking through WBAN WSN cooperation!
WSNs For Indoor Localization

RF tracking
- Low-cost, Low-size, Low-Power consumption
- Autocalibration
- ID
- Privacy (Proprietary protocol vs. WiFi)
- Wearable

Applications:
- Context-aware service provisioning
- Security
- Authentication

Positioning Services

- Location service for position and context aware applications
  - Bluetooth based

- Personal positioning service
  - Proprietary hardware
  - Self-tuning
Bluetooth based positioning

- When user moves indoor, the system can localize and recognize him and trigger context-dependent events (e.g. switch off the light of other rooms, open the favorite web page on palmtop...)
- The positioning system requires an infrastructure made by simple, cheaper and non-intrusive BT dongles
- About 1m accuracy (with proper positioning of dongles)

Integration: location aware HCI

- The issue: interacting with the computer … yes, but which computer?
- RF positioning WSN gives this information
- Seamless transition
  - Computer is proximity aware
  - No need for complex connections and disconnections
  - Session data is maintained
Pushing the envelope: Extra Eyes!

- Wideband sensors: CMOS imagers
  - KBPs wireless link BW for MBPs output BW
- Requires significant processing in-situ
  - Compression does not solve the problem for multiple sensors
  - Pattern recognition is the objective: “WSN vision”
- Exploring Hybrid configurable architectures

Video Node: Applications

- Wireless transmission of full QVGA Color Image @ slow frame rate
- Features extraction through SVM

Wireless transmission of the feature
**Video Node: current status**

**Characteristics:**
- Image resolution: QVGA
- Format: YUV
- Clock: 24MHz
- Camera Frame Rate: 25 fps

**Power dissipation TX:**

<table>
<thead>
<tr>
<th>Function</th>
<th>I (mA)</th>
<th>P (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition and storage</td>
<td>125</td>
<td>410</td>
</tr>
<tr>
<td>Reading, Compression and sending</td>
<td>114</td>
<td>377</td>
</tr>
<tr>
<td>Average</td>
<td>116</td>
<td>382</td>
</tr>
</tbody>
</table>

**Conclusion**

- BWANs open up a number of research and market exploitation opportunities
- Integration with “traditional” WSNs is the next frontier for system integration research
- Wideband nodes and ultra-low power in-situ processing give exciting challenges for node HW architecture design