Wireless Sensor Networks and RFIDs

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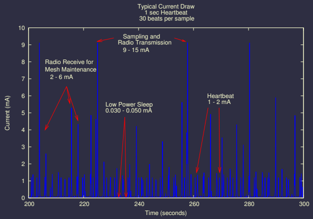


Collaborators

Projects in close collaboration with

- Lan Bai
- Peter Dinda
- Charles Dowding
- Sasha Jevtic
- Mat Kotowsky
- Lei Yang

Outline

Section outline

1. Wireless sensor networks
   - Introduction
   - MEMMU: Memory expansion for MMU-less embedded systems
   - Lucid dreaming: low-power sensing of unpredictable events

Wireless sensor networks

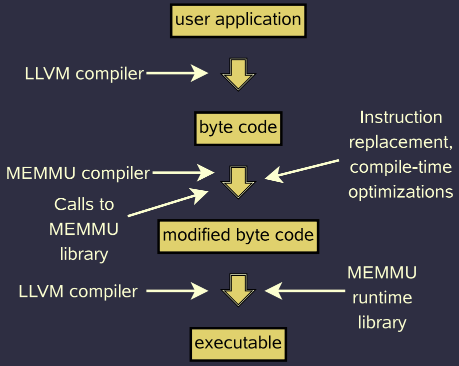
Self-organized wireless networks of sensors

Extremely tight resource constraints

- Limited performance processor
- Memory constraints, e.g., 10 KB
- Energy constraints
- Price limitations

Section outline

Memory expansion for MMU-less embedded systems



Observations and Results

- Application: Sensor networks
- Implemented in LLVM, tested on TelosB nodes
- Increases usable memory by 40%, unchanged applications
- Little overhead after compiler optimizations
- CASES'06

Original code

Variable: array $A[N]$
  for $i \in \{0 \cdots N\}$ **do**
    $A[i] \leftarrow x$
  end for

Transformed w.o. optimization

Variable: array A allocated by vm_malloc(N)
  for $i \in \{0 \cdots N\}$ **do**
    check_handle($(A + i)/PAGESIZE$)
    write_handle($A + i,\ x$)
  end for

Loop transformation

Variable: array A allocated by vm_malloc(N)

$pnum \leftarrow A/PAGESIZE$

for $i \in \{A/PAGESIZE \cdots (A+N)/PAGESIZE\}$ **do**

check_handle($pnum$)

for $j \in \{0 \cdots PAGESIZE\}$ **do**

write_handle($A + i \times PAGESIZE + j,\ x$)

$pnum{+}{+}$

end for

end for

With loop transformation and pointer dereferencing

Variable: array A allocated by vm_malloc(N)

$pnum \leftarrow A/PAGESIZE$

for $i \in \{A/PAGESIZE \cdots (A+N)/PAGESIZE\}$ **do**

check_handle($pnum$)

$base\_ptr \leftarrow$ virtual_to_physical($A + i \times PAGESIZE$)

for $j \in \{0 \cdots PAGESIZE\}$ **do**

$*base\_ptr \leftarrow x$

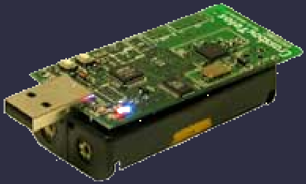
$base\_ptr{+}{+}$

$pnum{+}{+}$

end for

end for

Experimental setup



TelosB wireless sensor node

TI MSP430, 10 KB RAM

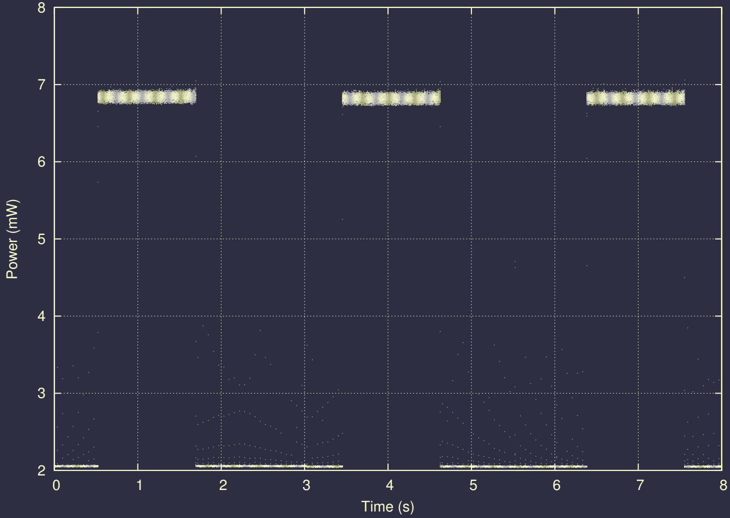
Power measurement

National Instrument 6034E data acquisition card

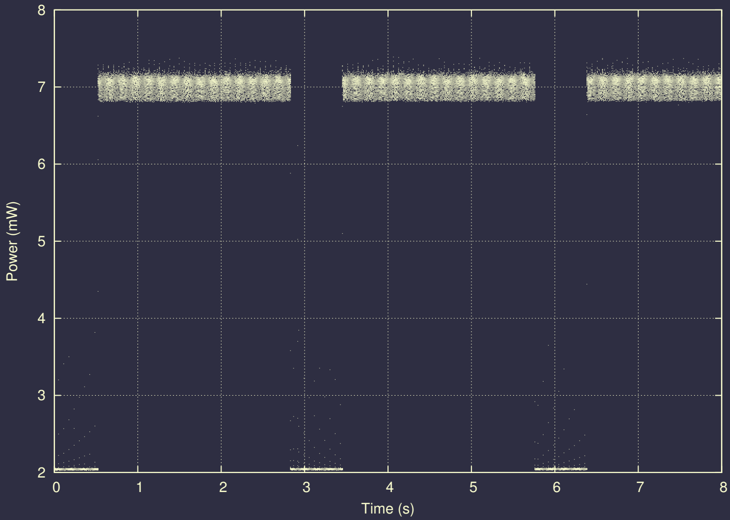
Metrics

- Memory expansion proportion
- Power consumption
- Execution time

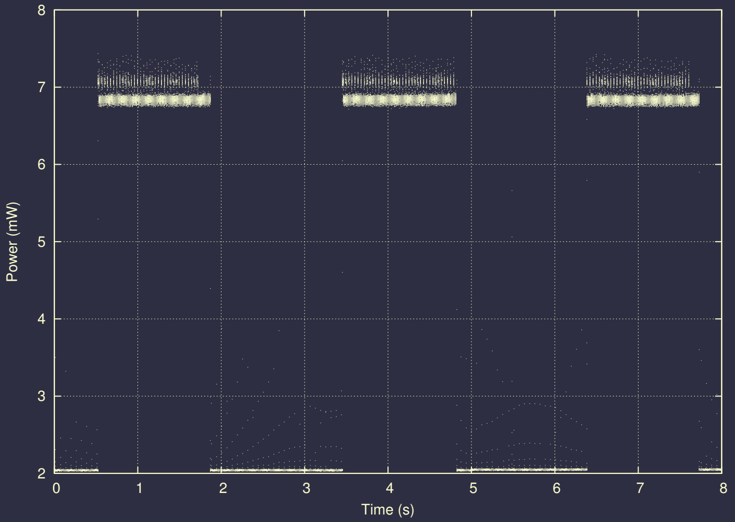
Power measurements for convolution application



With on-line software data compression



After compiler optimizations



Experimental results

- Increases usable memory by 40% on average with less than 10% overhead for all but one application
  - Pointer dereferencing optimization couldn't be used for image convolution
  - Performance overhead therefore high for that application
- Memory expansion will increase with increasing physical RAM
  - Will approach 100% given current compression ratio

Section outline

Low-power event-driven applications

- Conventional sensor network operation: poll and sleep
- Many real applications must detect unpredictable events
- How?

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Periodically awaken?

Misses events

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Misses events

Always remain awake?

Two days of battery life

Low-power event-driven applications

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- Many real applications must detect unpredictable events
- How?

Periodically awaken?

Misses events

Always remain awake?

Two days of battery life

Goal

Always awake but with ultra-low power consumption

Application: Structural integrity monitoring

- Buildings and bridges have cracks
- Most not dangerous, but could become dangerous
- Widths change in response to vibration
- 300 μm common, 3$\times$ width of human hair

Detecting dangerous conditions

Inspectors monitor cracks to determine when dangerous

- Expensive
- Infrequent

Could use wireless sensor networks

- Inexpensive
- Constant

Problem: Event-driven application. Only a few days of battery life.

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Past structural integrity work

- N. Kurata, et al., "A study on building risk monitoring using wireless sensor network MICA mote," in *Proc. Int. Conf. on Structural Health Monitoring and Intelligent Infrastructure*, Nov. 2003, pp. 353–357
- J. P. Lynch, et al., "The design of a wireless sensing unit for structural health monitoring," in *Proc. Int. Wkshp. on Structural Health Monitoring*, Sept. 2001
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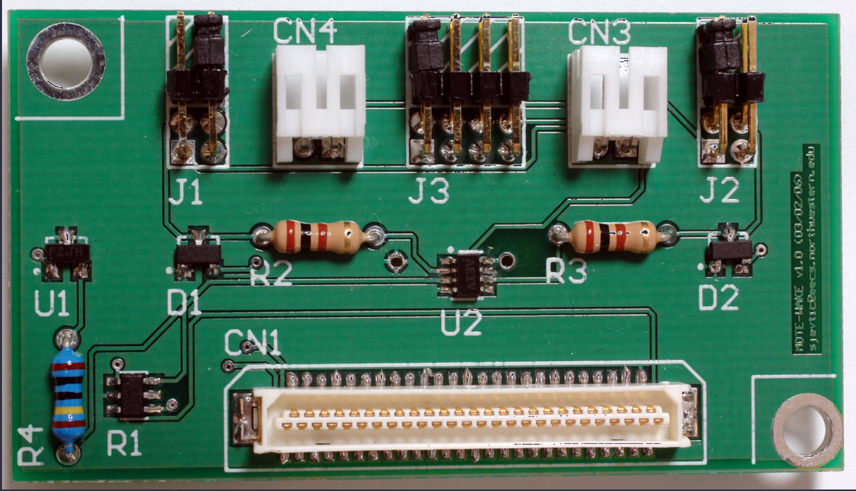
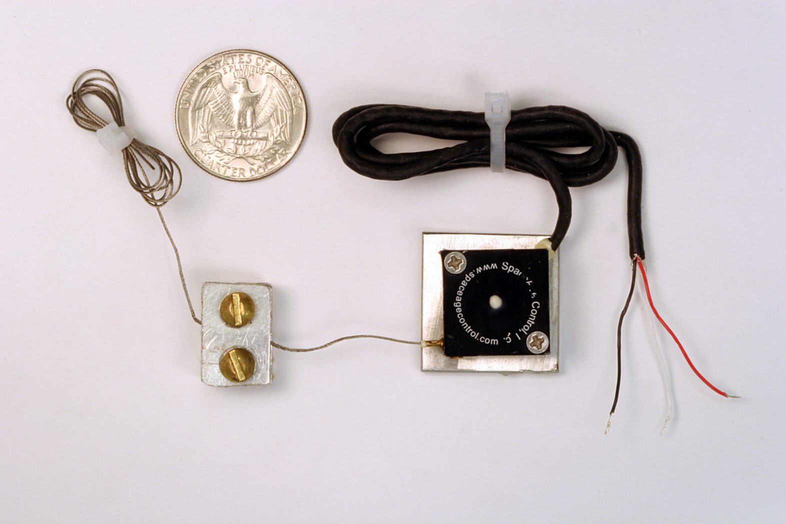
Short battery life. Two-day deployments and explosives.

Circuit board



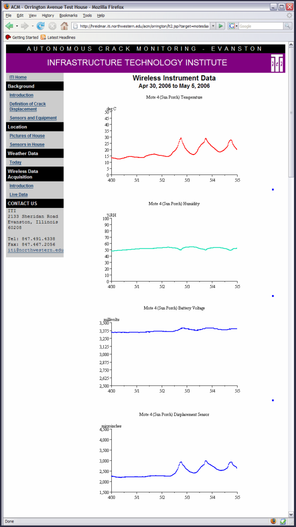
Board and large geophone

Primary sensor

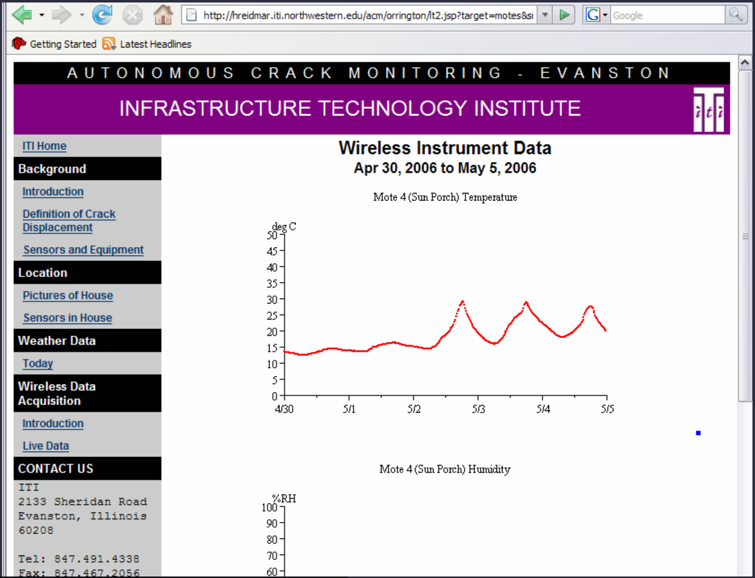


System in case

Web interface screen shot



Web interface screen shot



Power reduction

- Always on: 24 mW
- Lucid dreaming hardware: 16.5 μW
- Best existing work: 2.64 mW
- Lucid dreaming in system: 121.8 μW

Implications and status

Original situation

Missed events or battery replacement after a few days

Current status

- Battery life of months
- Many boards fabricated
- Deployed in multiple buildings already
- Public real-time web interface for data
  - http://iti.birl.northwestern.edu/acm/