Harvesting energy for measurement and persistent display

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Outline

1. Introduction and motivation
2. e-paper technology
3. Technical challenges
4. Our solution
5. Results and measurements
6. Conclusion

Source: ZHAW
Our Activities

Institute of Embedded Systems

Core Competences

• FPGA-based systems for network communication
• Time synchronization and high availability Networks
• Real-Time-Ethernet, safe and dependable Systems
• **Wireless Communication**
  ➢ Low Power, Energy Harvesting, Power mgt
  ➢ Different wireless/RFID systems

Source: ZHAW
Our Activities: example of demonstrator

LED powered energy autonomous sensor for BLE

- Energy from 4 red LEDs
- Sends data using BLE ADV frames
- Update rate of less than a minute possible
- Works well outdoors and also works indoors
- Architecture/development from ZHAW
- Radio and microcontroller from EM Marin

Source: ZHAW
Our Activities: example of demonstrator

Dynapic Wireless

- Press to send a wireless message
- Solely powered by piezo energy
- Thin, robust, small, adaptable
  - Fits on many surfaces
  - No clicks
  - Over 10’000’000 key presses

- Cooperation
  - Algra, Microdul, ZHAW

Source: ZHAW
Introduction and motivation

• One essential part of energy harvesting sensor systems is the data communication

• Most common ways for data exchange
  ➢ Wireless communication:
    o Data transmitted over BLE, ZigBee, LoRa, NFC ...
    o Requires receiver (e.g. smartphone)
    o Data can be saved locally and transferred later for analysis
  ➢ Wired communication:
    o I2C, SPI, UART,...
    o Wiring means less flexibility

• What other interfaces might be possible?
Introduction and motivation

• Some applications have different requirements
  - Constant measuring and/or logging is not needed
  - Use of external receiver not desired or possible
  - Data only has to be available on demand
  - No power supply available
  - Use of batteries is not desired
Introduction and motivation

- Displays can be used to show data on demand without the need for external devices
  - Most commonly used technologies are LCD, OLED, TFT, ...
  - But, ...
    - Energy consumption is a big challenge
    - Constant energy is required to keep display on and show data
    - Energy harvesting is generally not sufficient to cover the energy needs -> battery is required
- Possible solution: e-paper displays
e-paper technology

- Electronic paper
- Segments filled with charged black and white particles
- Applying voltage with different polarity
- Display update in two steps
- Operating voltage 5-15V
- Driving times: 500ms – 2s @ 5V, 240ms @ 15V
- Current consumption during display transitions: 500nA / cm²

Images source: Eink
e-paper technology

- Advantages
  - Very low energy consumption
  - Energy is only consumed during display transition
  - Display can retain its state when power is absent
  - Displays are very customizable, any 2-D shape is possible
  - No backlight, however some external light is required to read

Source: Eink
Technical challenges

• Despite its great advantages, there are some challenges working with e-paper displays

• **Challenge 1: High supply voltage**
  - At least 5V required to provide good contrast and prevent ghosting
  - EH and power management has to deliver 5V
  - Components have to be 5V compatible
  - Higher energy consumption due to higher voltage
Technical challenges

• Challenge 2: Long driving times
  ➢ At 5V driving time is at least 1s for an update (clear and write)
  ➢ Compared to Dynapic wireless (<4 ms)
  ➢ More time means more energy
  ➢ Very low active and quiescent energy consumption of components required

• Challenge 3: Amount of control lines
  ➢ Every display segment needs an own control line
  ➢ Lot of MCUs do not have enough output pins
Our solution

Block diagram

- **piezo**
- **PM ASIC**
- **MCU ASIC Master**
- **MCU ASIC Slave**
- **Thermistor**
- **e-paper display**

Red lines indicate **Power** connections, while black lines indicate **Signal** connections.
Our solution

Energy Harvesting & power management

- Dynapic piezo as energy source
  - High voltage but low current. Very little energy available
  - Easy to use, no environmental requirements
- PM ASIC
  - High input impedance
  - Allows piezo to go higher in voltage
  - Provides >5V supply voltage
  - Ultra-low-power voltage monitoring
Our solution

E-paper display

- 3-digit display with one decimal
- Only 23 control lines needed to display values

MCU

- Low-power ASIC MCU
- Fast start-up procedure
- Low energy consumption in active and sleep mode to compensate long driving times
- Can be operated at >5V
- Two MCUs required to have enough pins for display
- ADC input for temperature measurement with thermistor
Results and measurements

- Powered only by Dynapic piezo, no batteries required
- Press to measure and display result
- Measures temperature with a thermistor
- Low power embedded system
- Results remain on display until next measurement is triggered
- Voltage is high enough to provide good contrast on display

Source: ZHAW
How much energy is needed to do the work?

• Includes startup, measure, clear and write display

• Total energy consumption: 7nWh -> ~25 microJ
Results and measurements

- **Energy consumption profile**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Duration</th>
<th>Energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Startup and measure</td>
<td>13 milliseconds</td>
<td>4 microJ</td>
</tr>
<tr>
<td>Clear display</td>
<td>580 milliseconds</td>
<td>10 microJ</td>
</tr>
<tr>
<td>Write display</td>
<td>560 milliseconds</td>
<td>7 microJ</td>
</tr>
<tr>
<td>Discharge capacitor</td>
<td>10 milliseconds</td>
<td>4 microJ</td>
</tr>
</tbody>
</table>

- **Most energy is used during display transitions**
  - Both MCU are in sleep mode but for more than 1s
  - E-Ink display only consumes around 1 microJoule during 500ms (depends on value displayed)
  - Using only one MCU with enough pins and similar ultra-low-power performance could reduce energy consumption
Conclusion

What we have achieved:

- Low-power embedded system displaying measurement on a e-paper display
- Energy harvested from a piezo, no batteries required
- Energy consumption < 30μJ
- Potential cost is low
- We don’t know any other system using e-paper technology powered only by EH
Conclusion

What can be done:

• Using other sensors for different applications
  ➢ Humidity, pressure, water quality, ...
• The flexibility of e-paper allows a lot of different ways to display information
Questions

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