Data Compression Processor for Biomedical Information Sensing Platform

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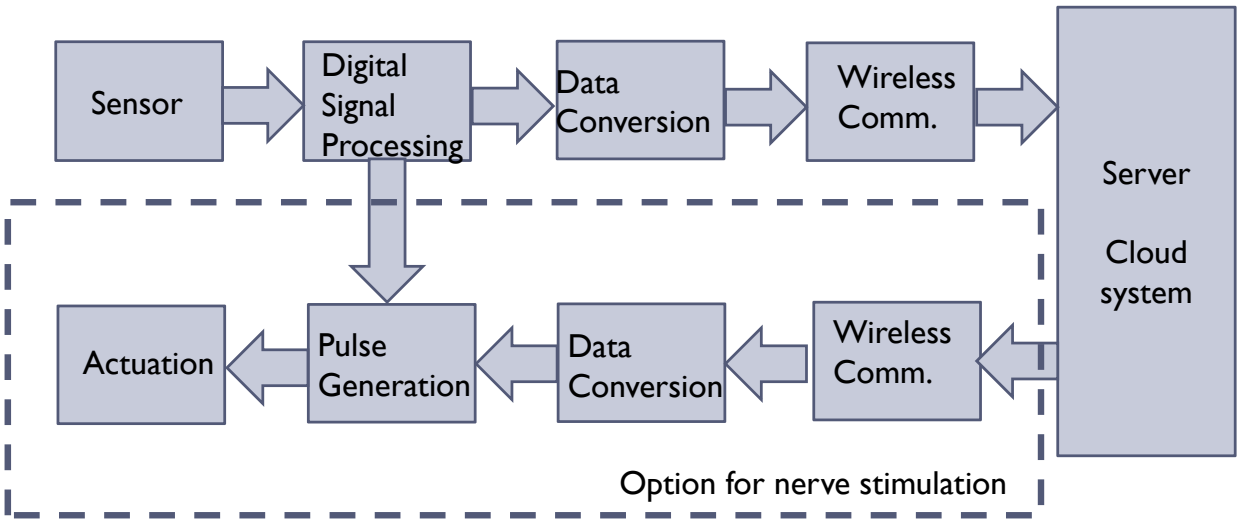
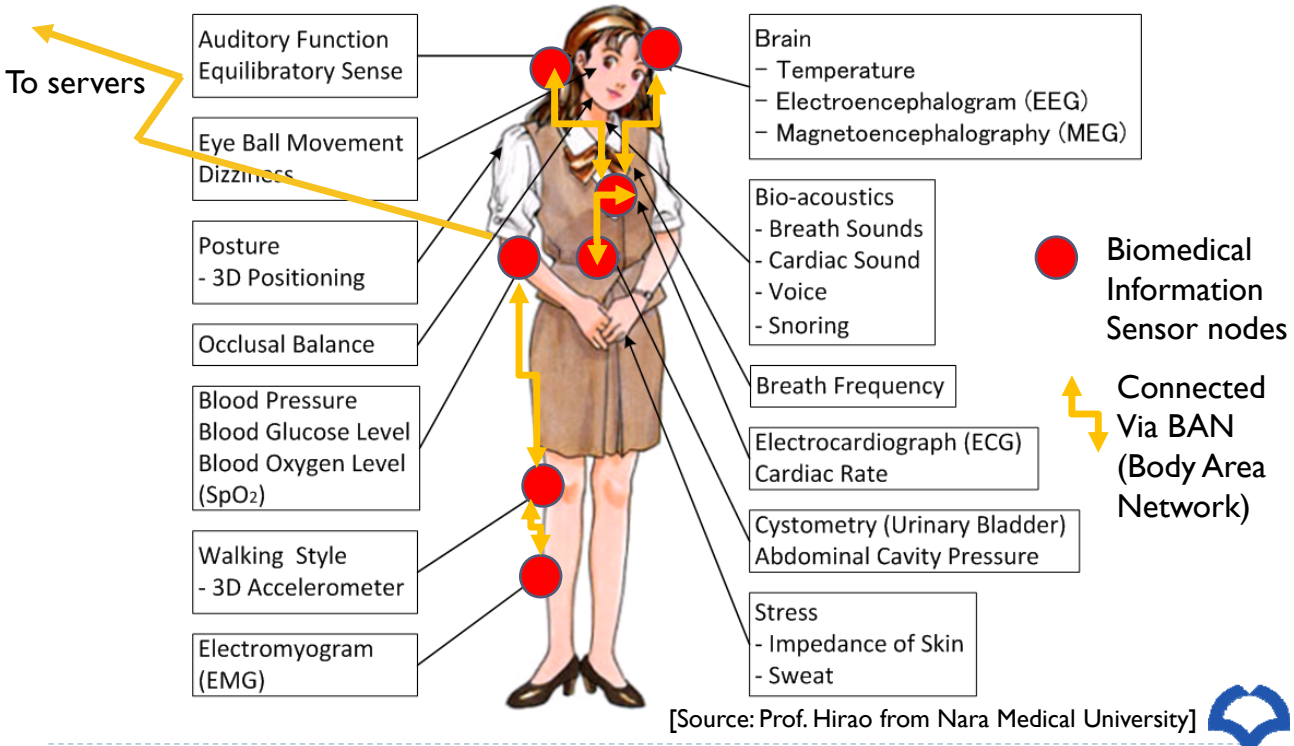
Biomedical information sensing node



Biomedical Information from Human Body



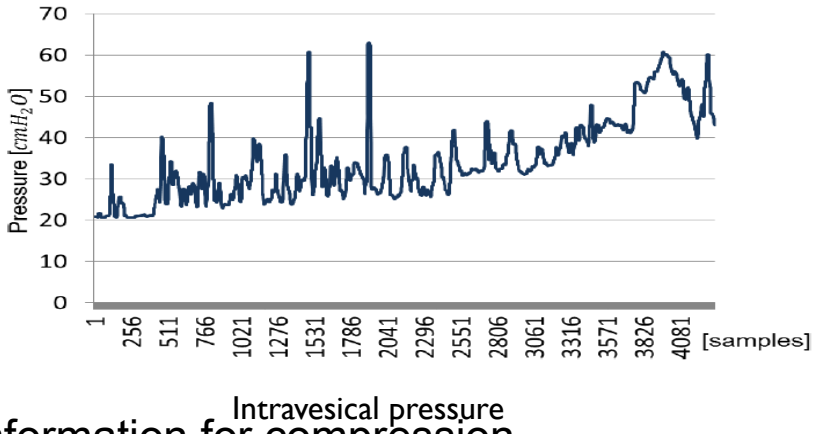
[Source: Prof. Hirao from Nara Medical University]

Biomedical information sensing system

- A lot of small nodes (processors) are embedded into the body
- Data is transferred by wireless communications
- Small size/ long term operation should be required
- Systems should handle huge amount of data
  - Large storage size
  - Long time and large energy consumption for data transmission

- Low power/energy data compression method and implementation
  - Especially, lossless data compression
    - Data is used for diagnosis and treatment of disease

Example of Biomedical information



Intravesical pressure

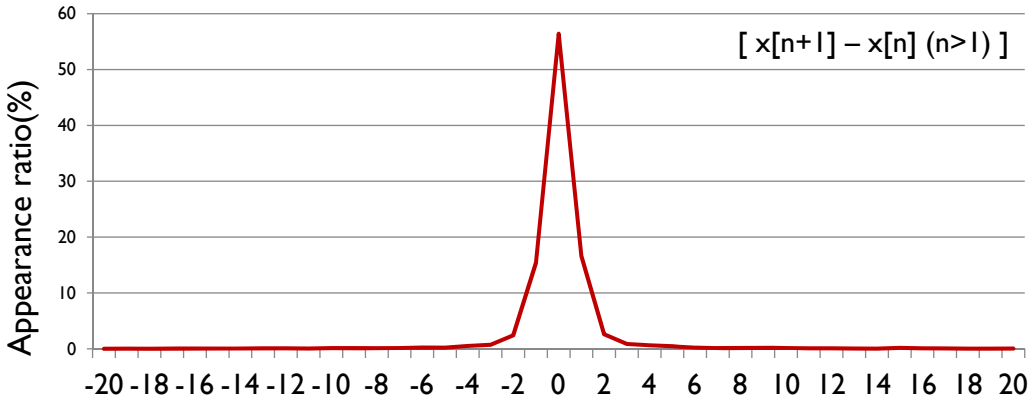
- Target information for compression
  - Time series of biomedical information
    - Inner body pressure, ECG (Electrocardiogram), and EEG (Electroencephalogram)
    - Intravesical and rectum pressures
      - Accuracy is 10 bit
      - Sampling interval is 120 [msec]

Conventional data compression methods

- Huffman coding
- Adaptive Huffman coding
- Arithmetic coding
- Dictionary-style coding
- miniLZO [1]
  - One of the most efficient data compression algorithms
  - Used for the biomedical information compression

[1] " Oberhumer.com GmbH, LZO Professional data compression library, "
http://www.oberhumer.com/

Distribution of differences between consecutive data



- Small absolute values appear more frequently
  - Taking this characteristic into consideration in proposed encoding methods

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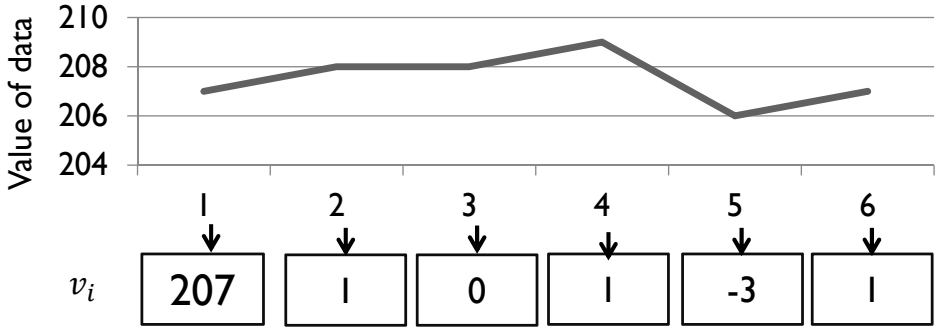
Proposed compression method (1/3)



1. Computation of difference value
   - The proposed method uses difference value between consecutive pressure data
   - Let an integer $u_i \geq 0$ be the $i-th$ input data, where $i > 0$
     - The difference value v_i is calculated
       - $v_i = u_i - u_{i-1}, i > 0, u_0 = 0$

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Proposed compression method (2/3)

- 2. Mapping to non-negative integer
  - v_i can be a negative value
    - Exponential-Golomb coding cannot handle negative values
    - v_i is mapped to a non-negative integer w_i
      - $w_i = \begin{cases} 2|v_i| & (v_i \geq 0) \\ 2|v_i| - 1 & otherwise \end{cases}$

v_i	w_i
0	0
-1	1
+1	2
-2	3
+2	4
-3	5
+3	6

Proposed compression method (3/3)

3. Exponential-Golomb coding
  - Encoding steps of exponential-Golomb coding
    - Let w be the input to encode, and k be the parameter
      1. Determine i that satisfies the following inequation
         - $\sum_{j=0}^{i-1} 2^{j+k} \leq w < \sum_{j=0}^{i} 2^{j+k}$, $i \geq 0$
      2. Form the prefix of i 1s to codeword
      3. Append the separator 0 to the end of prefix
      4. Calculate the value of
         - $\mathrm{w} - \sum_{j=0}^{i-1} 2^{j+k}$

         as a $k + i$ bit binary number, and append it after the separator 0

Metrics of Compression (1/2)

1. Compression Ratio

$$CR = D_o / D_c$$

D_o: Raw data size
D_c: Compressed data size

2. Compression Error

Percentage Root-mean-square Difference (PRD)

$$PRD = 100 \times \sqrt{\sum_{i=1}^{N} (x_i - y_i)^2 \Big/ \sum_{i=1}^{N} {x_i}^2}$$

xi: Raw data, yi: Reconstructed data from compressed data

Metrics of Compression (2/2)

3. Power consumption

4. Energy consumption

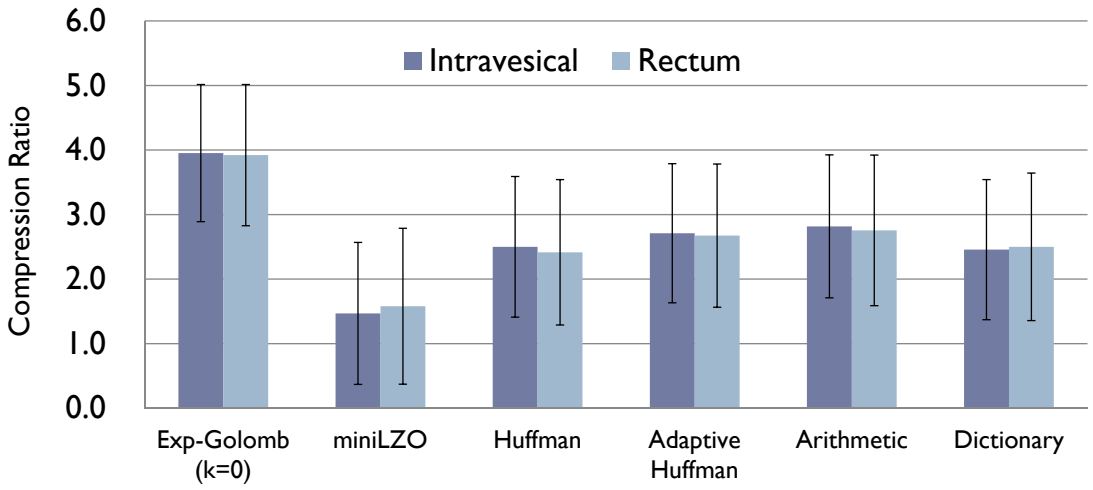
Comparison of Compression Ratio

- Exponential Golomb shows the highest compression ratio among others.

Data	Golomb (m=3)	Golomb-Rice (k=1)	Exponential Golomb (k=0)	Semi-Exponential Golomb (k=0)
Intravesical Pressure	3.23	3.13	3.95	3.89
Rectum Pressure	2.92	2.69	3.92	3.83
Harmonic Average	3.06	2.89	3.94	3.86

Comparison of Compression Ratio against Conventional Methods

- Exponential Golomb coding shows the largest and more stable compression ratio.



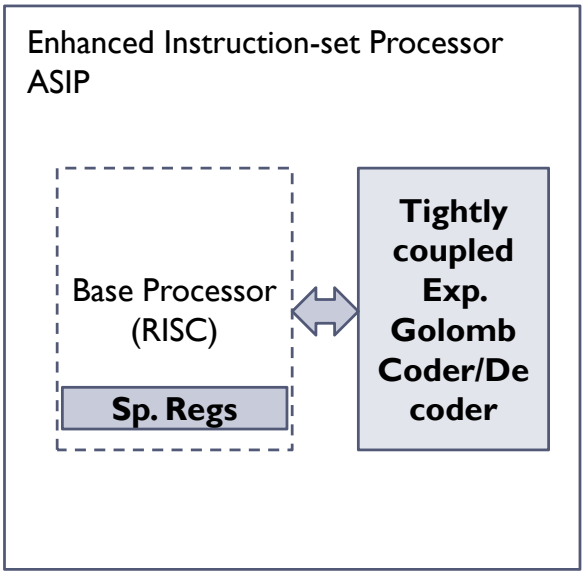
Requirements to data compression in biomedical information sensing systems

- Most of the biomedical information sensing systems use instruction set processors
  - Originally, control sensor devices, analog to digital converter (ADC), peripherals, and data communication
- Data compression algorithms perform bit manipulation operations frequently
  - Conventional RISC processors or so-called general purpose processors (GPP)
    - Require many execution cycles and large energy consumption to handle bit manipulation operations

ASIP implementation for exponential-Golomb code

- Application domain specific instruction set processor (ASIP)
  - Enables high performance per chip area
  - Achieves high performance per energy consumption
- Implementation for exponential-Golomb coding
  - Base processor : a 16 bit RISC processor Brownie Micro 16 (BM-16)
    - 33 RISC instructions, 16 general purpose registers, and three stage pipeline
  - To enhance the performance of BM-16
    - Added seven dedicated instructions

ASIP and compression



- Enhanced instructions
  - Instructions for Exp. Golomb Coding
  - Instructions for Exp. Golomb Decoding
  - Packing instructions
  - …

Experimental environment

- ASIP Meister (ASIP Solutions, Inc.)
  - Base processor : BM-16
- Design Compiler (Synopsys, Inc.)
  - 0.18 μm CMOS library
  - Operation voltage 1.8 [V]
  - Operation frequency 100 [MHz]
- ModelSim (Mentor Graphics Corp.)
- Test data
  - 8 sets of intravesical pressure
  - 8 sets of rectum pressure
  - Each set includes 1,000 samples

Results of proposed implementation

	RISC (A)	ASIP (B)	(B-A)/A (%)
Area (μm^2)	61,316	138,531	+126
Power (μW/MHz)	38.9	65.7	+69
Exec. Cycles	86,165	17,177	-80
Energy (μJ)	3.35	1.13	-66

Conclusion and future work

- Conclusion
  - Efficient lossless data compression method based on exponential-Golomb code was proposed
    - Proposed method takes advantage of the characteristics of target information
  - Implementation of a low energy consumption ASIP using dedicated instruction set for biomedical information compression was proposed
- Future work
  - Application of proposed compression method to other biomedical information
  - Total evaluation of biomedical information sensing system