Advanced exercise control using miniature ECG and 3D acceleration sensors

D&D Forum on Telemedicine Systems:
Issues, Design, Development and Standardization
at Globecom 2008

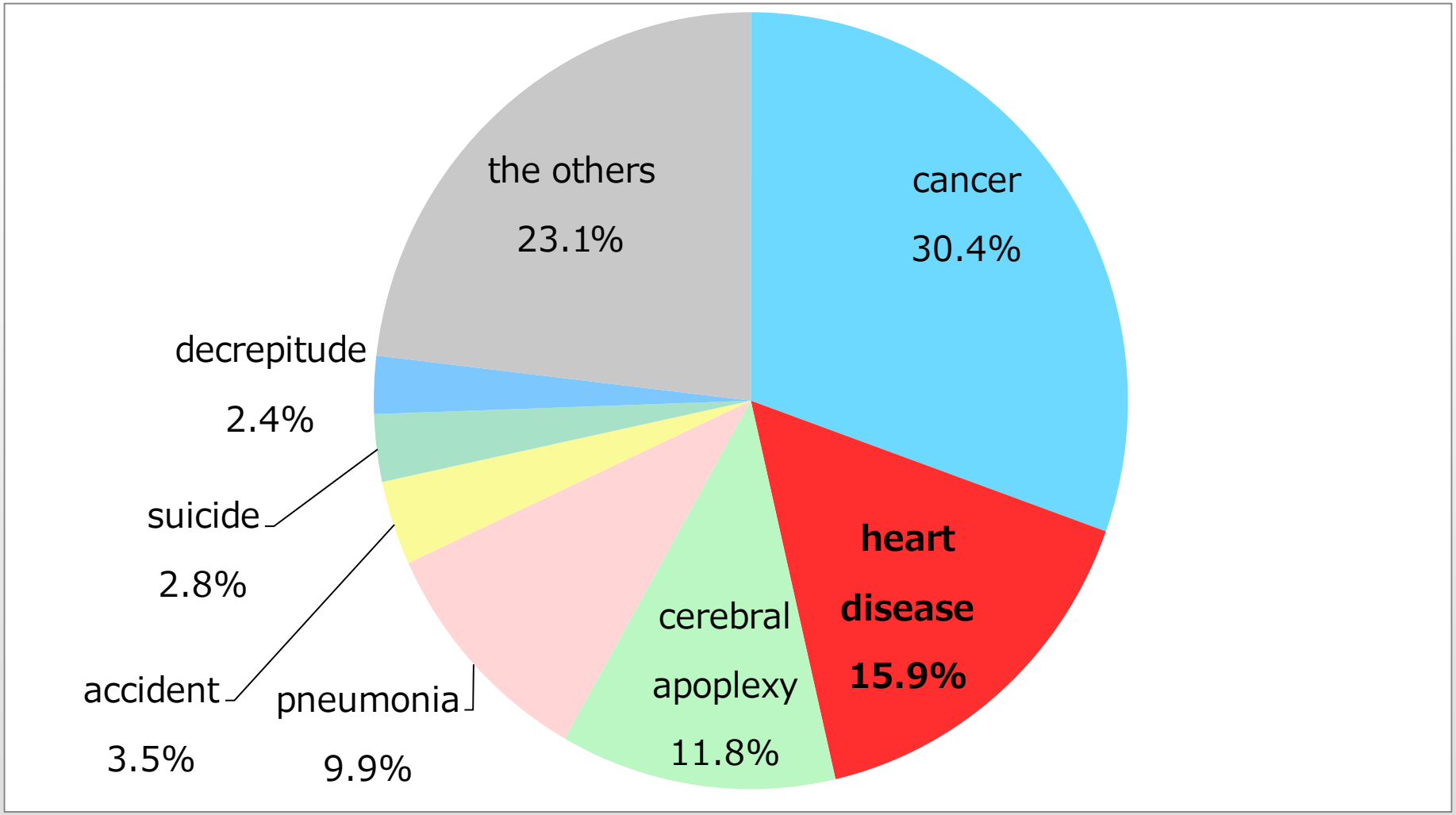
Dec 2, 2008
New Orleans, Louisiana, USA

*Toshinori Kagawa
*Makoto Kawashima
**Natsuki Nakayama
*Dept. Computer Science
**Dept. Nursing College Life and Health Sciences
Chubu University, Japan.

Table of Contents

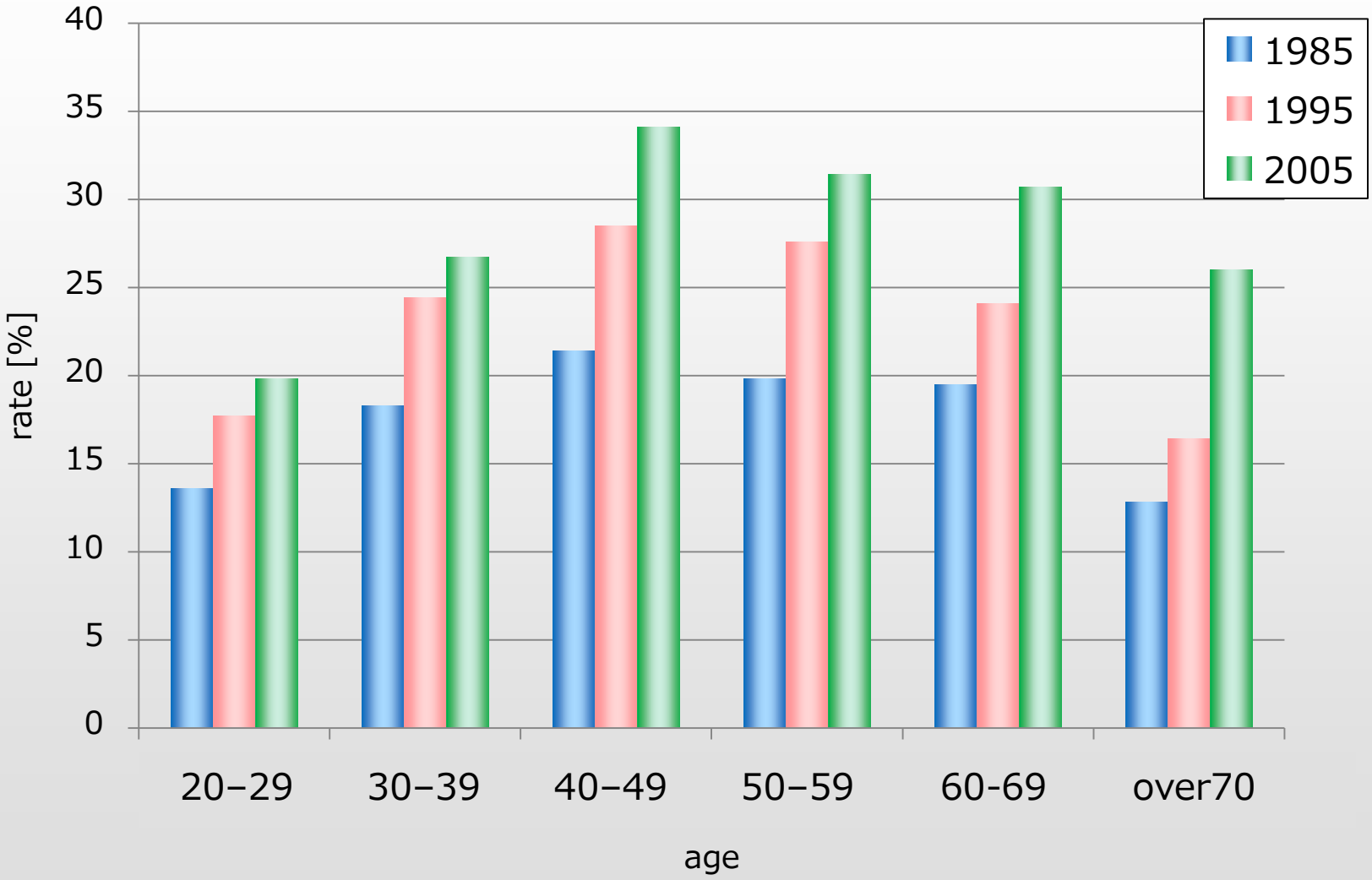
- Background
- Research Objectives
- Development of ECG and 3D acceleration based exercise sensor
- Life-time expansion of the sensor
- Conclusions
- Recent issues to be studied and application systems for the future

Mortality rate and cause of death



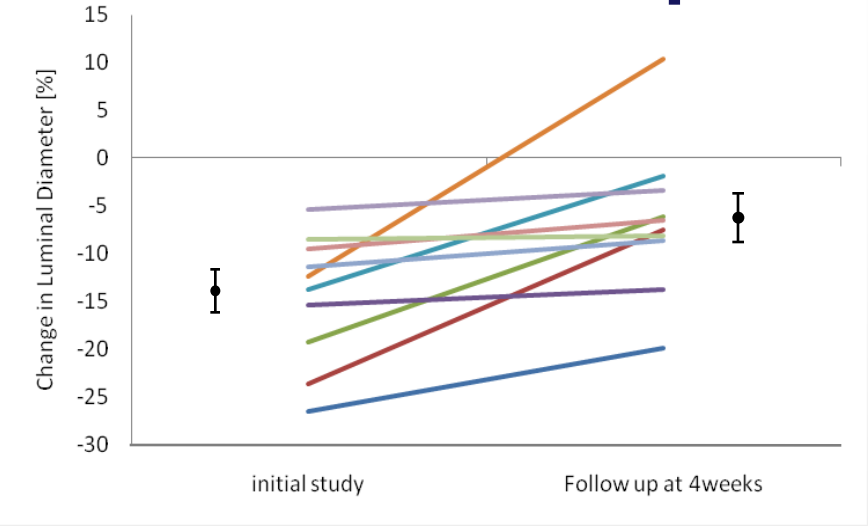
Ministry of Health, Labour and Welfare in Japan (2006)

Obesity rate (Body Mass Index≧25)

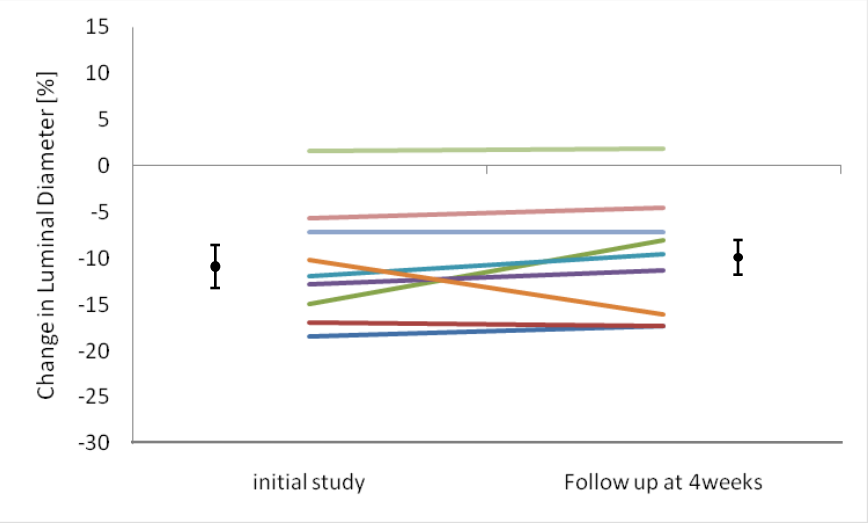


Ministry of Health, Labour and Welfare in Japan (2007)

Effect of appropriate exercise training for heart disease patients



Exercise training group

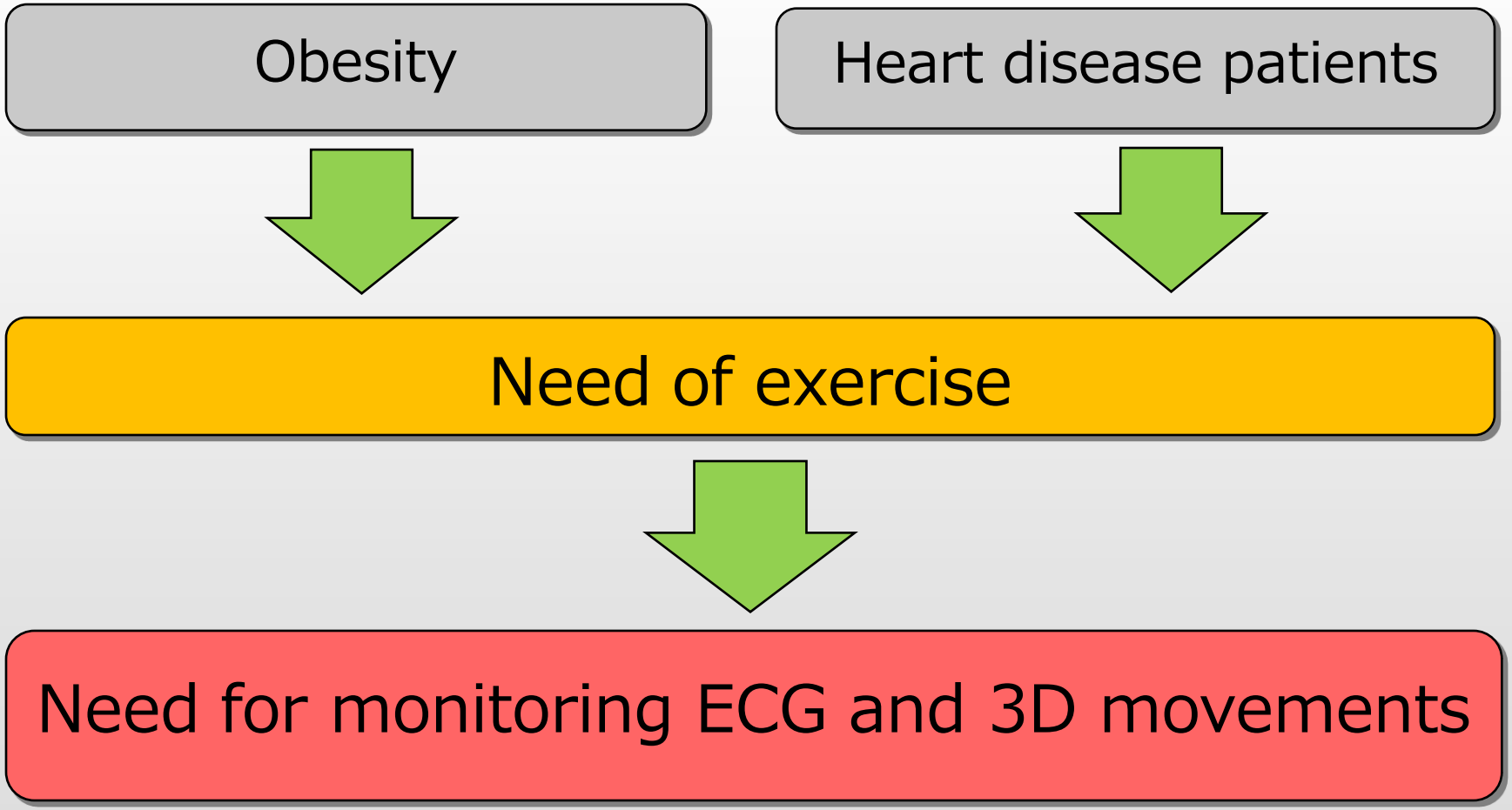


No exercise group

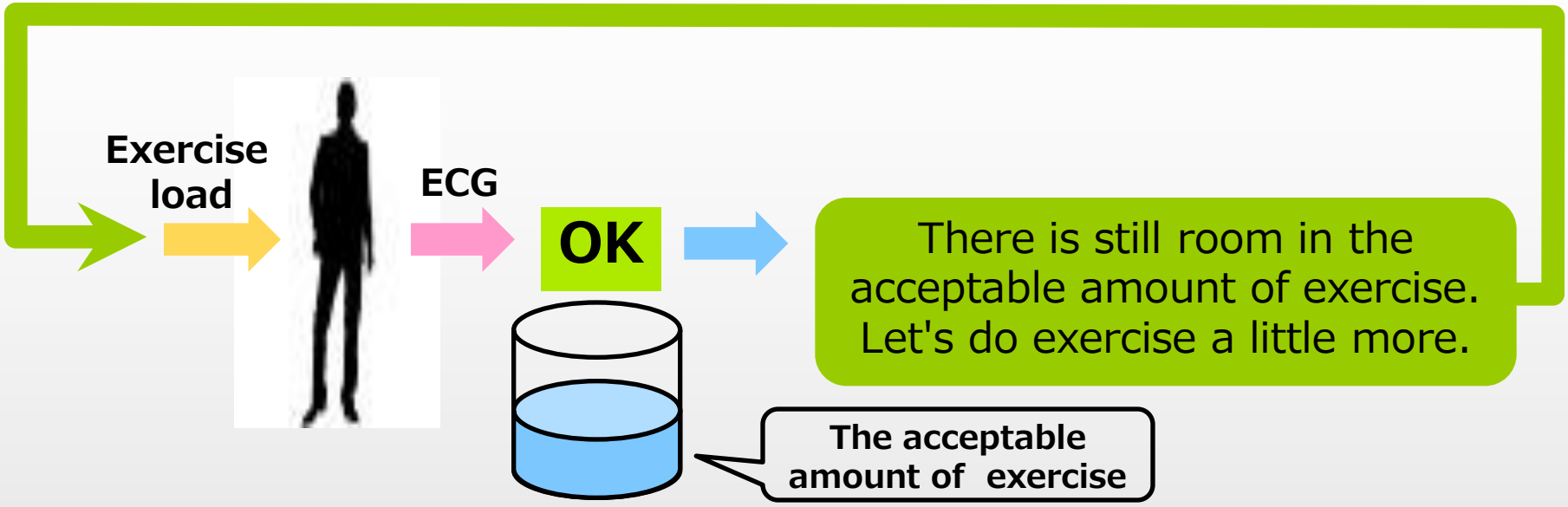
- Study condition
  - Total number of patients : 19 persons
    - Exercise training group : 10 persons
    - No exercise group : 9 persons
  - Estimation items :
    - Luminal diameter(left figures)
    - Coronary blood flow
- Discussed results
  - Both luminal diameter and coronary blood flow were apparently improved by appropriate exercise training

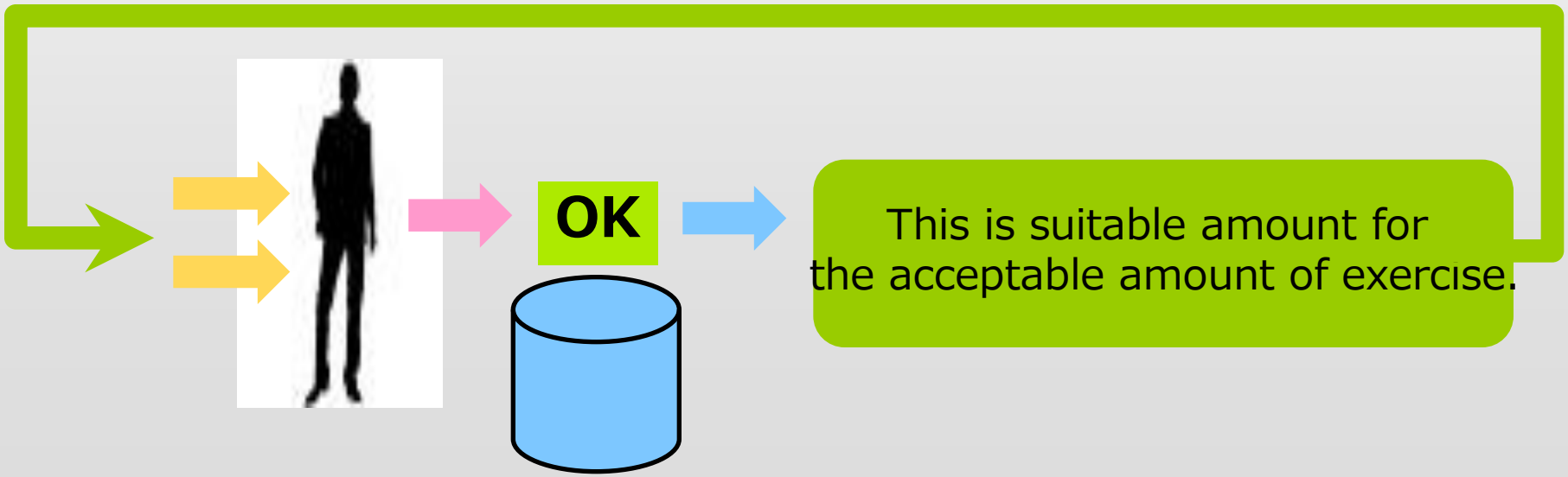
Rainer Hambrecht et.al, Effect of Exercise of Coronary Endothelial Function in Patients with Coronary Artery Disease, The New England Journal of Medicine, Feb. 2000

Necessity of the advanced exercise control by continuous vital signs monitoring



Feedback control for detection of suitable amount of exercise





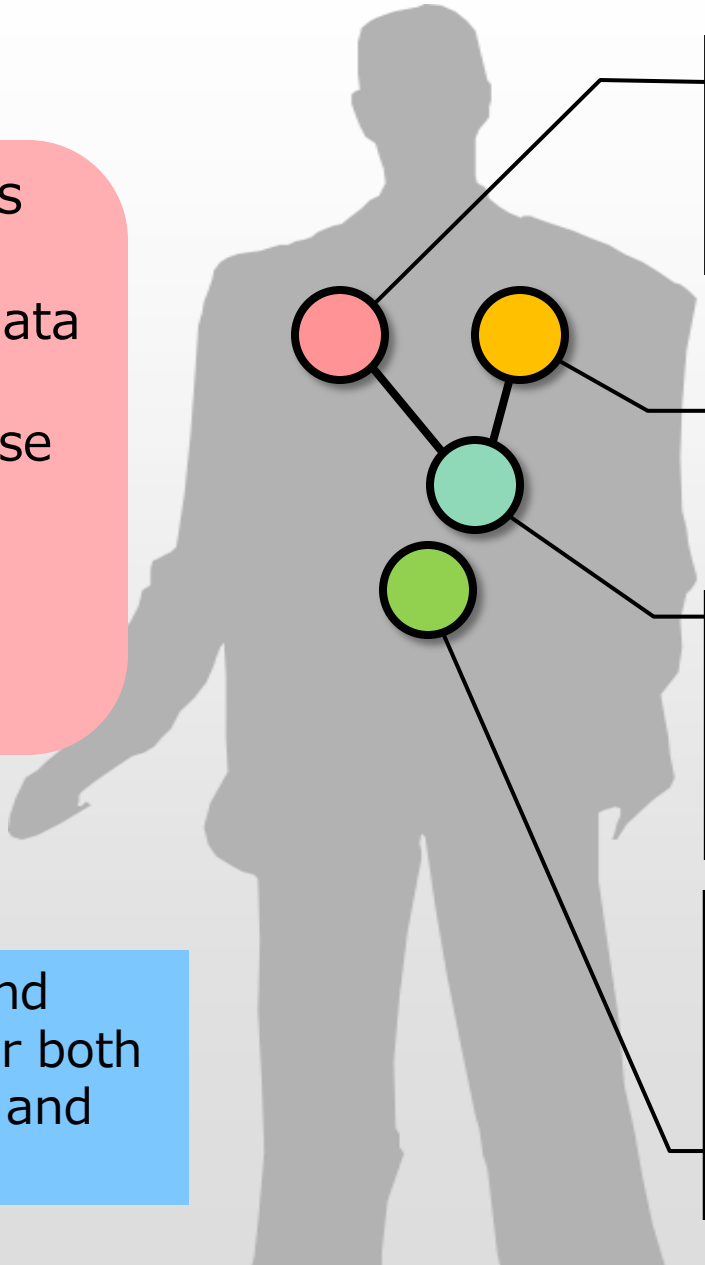
Research Objectives

- Development of ECG sensor and exercise amount sensor
  - Realization of long-life sensor operation
  - Small size and light weight sensors
- System proposal for a rehabilitation supporting system using ECG and exercise monitoring

Sensor allocation for the experimental system

Realized functions

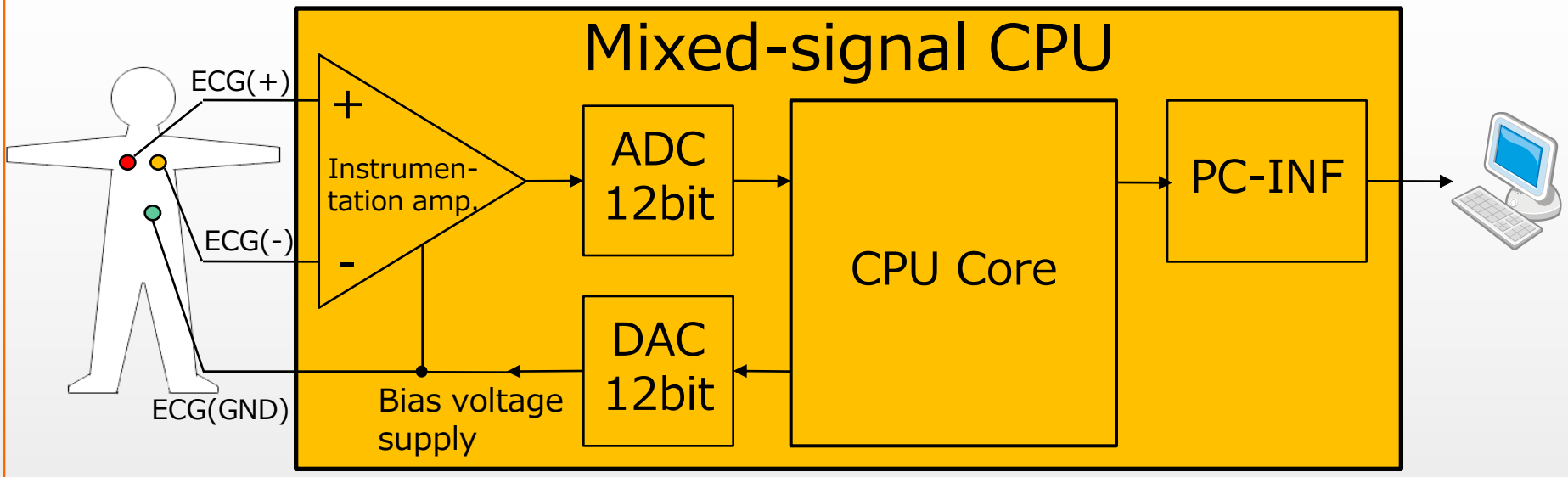
- Capturing ECG data
- Capturing exercise amount
- Communication with PC



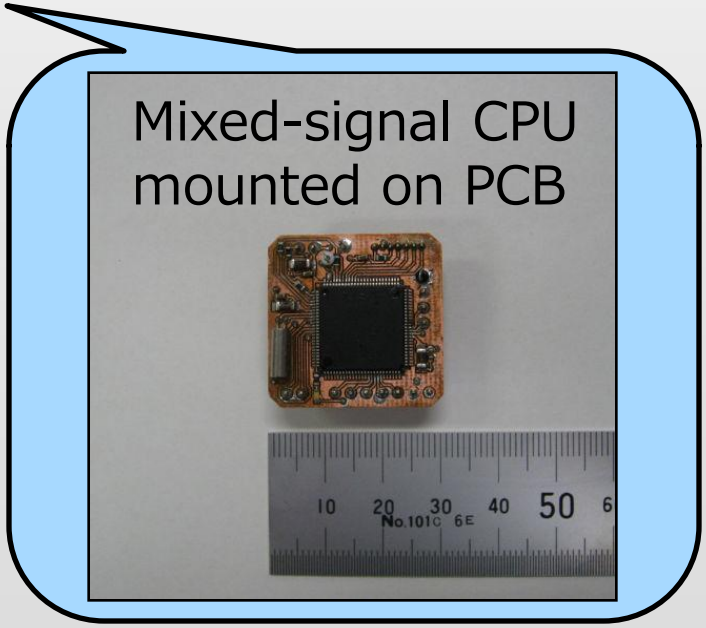
- ECG electrode (+)
- ECG electrode (-)
- ECG electrode (Ground)
  - Capturing ECG data
- Mixed-signal CPU
  - PC-NIF
- 3D acceleration sensor
  - Capturing acceleration data
- Mixed-signal CPU
  - Calculation of exercise amount

Analysis and monitor for both heart rate and exercise

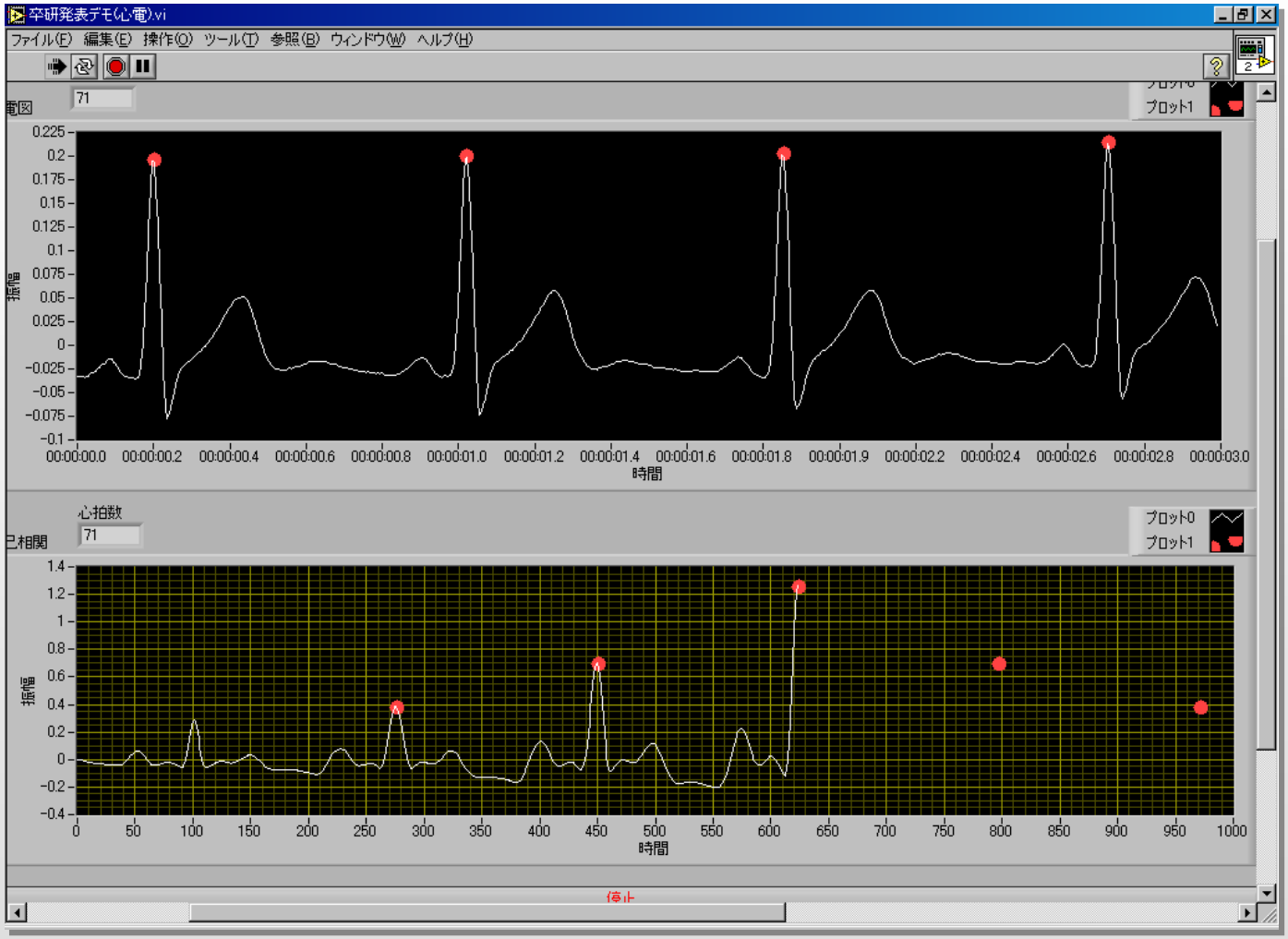
Experimental ECG sensors



- Three electrodes are attached on the chest
- Mixed-signal CPU chip is mounted on the ECG (Ground) electrode



Observed ECG data and its autocorrelation analysis



ECG data

autocorrelation

- Sampling rate:600Hz, quantization word length:12bit
- Autocorrelation gives heart rate

What is Metabolic Equivalent (METs*) ?

- METs is a measure for deriving exercise amount

Human activity	Walking (81m/min)	Brisk Walking (94m/min)	Running (134m/min)	. . .
METs value	3.3	3.8	8.0	etc.

Total amount of "***Exercise***" : E_{total}

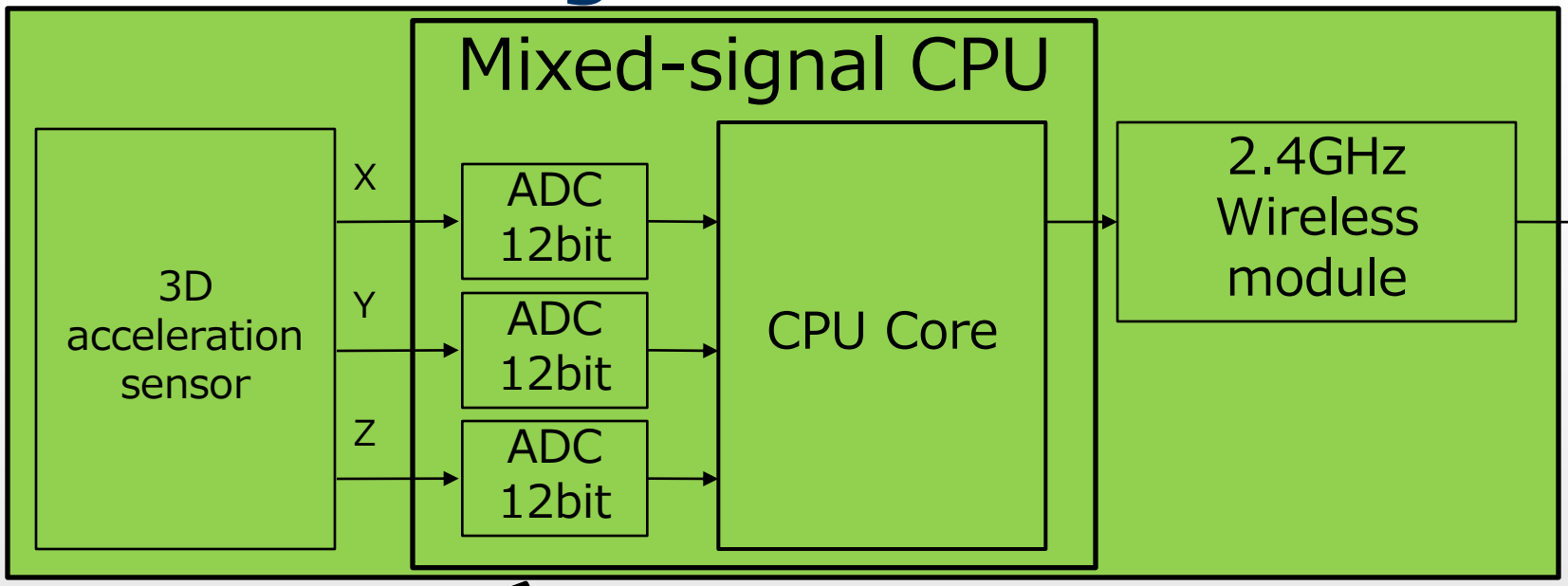
$$E_{total} = \sum_{i=0}^{n} M_i t_i$$

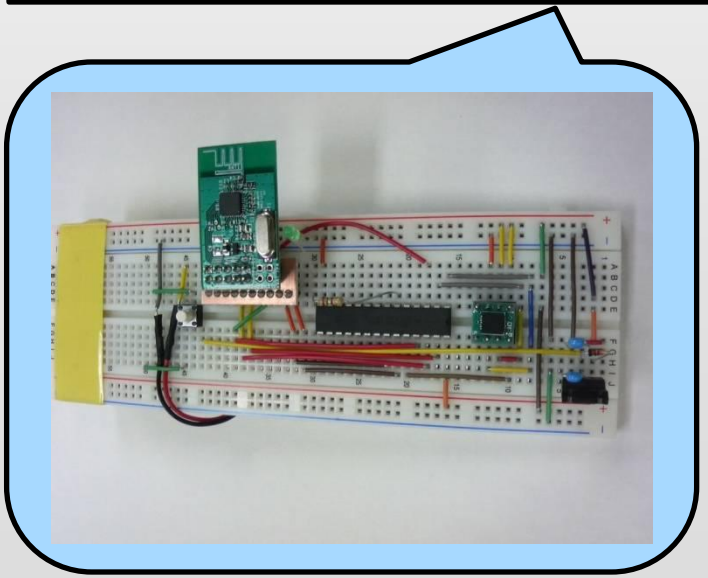
where E_{total} is total amount of exercise, M_i is METs value and t_i is time(hours)

Ex) Daily activity and the movement of
"23 ***Exercises***" a week are recommended in Japan.

* The definition of the METs is specified by the American College of Sports Medicine (ACSM)

Experimental 3D acceleration sensors for measuring exercise amount

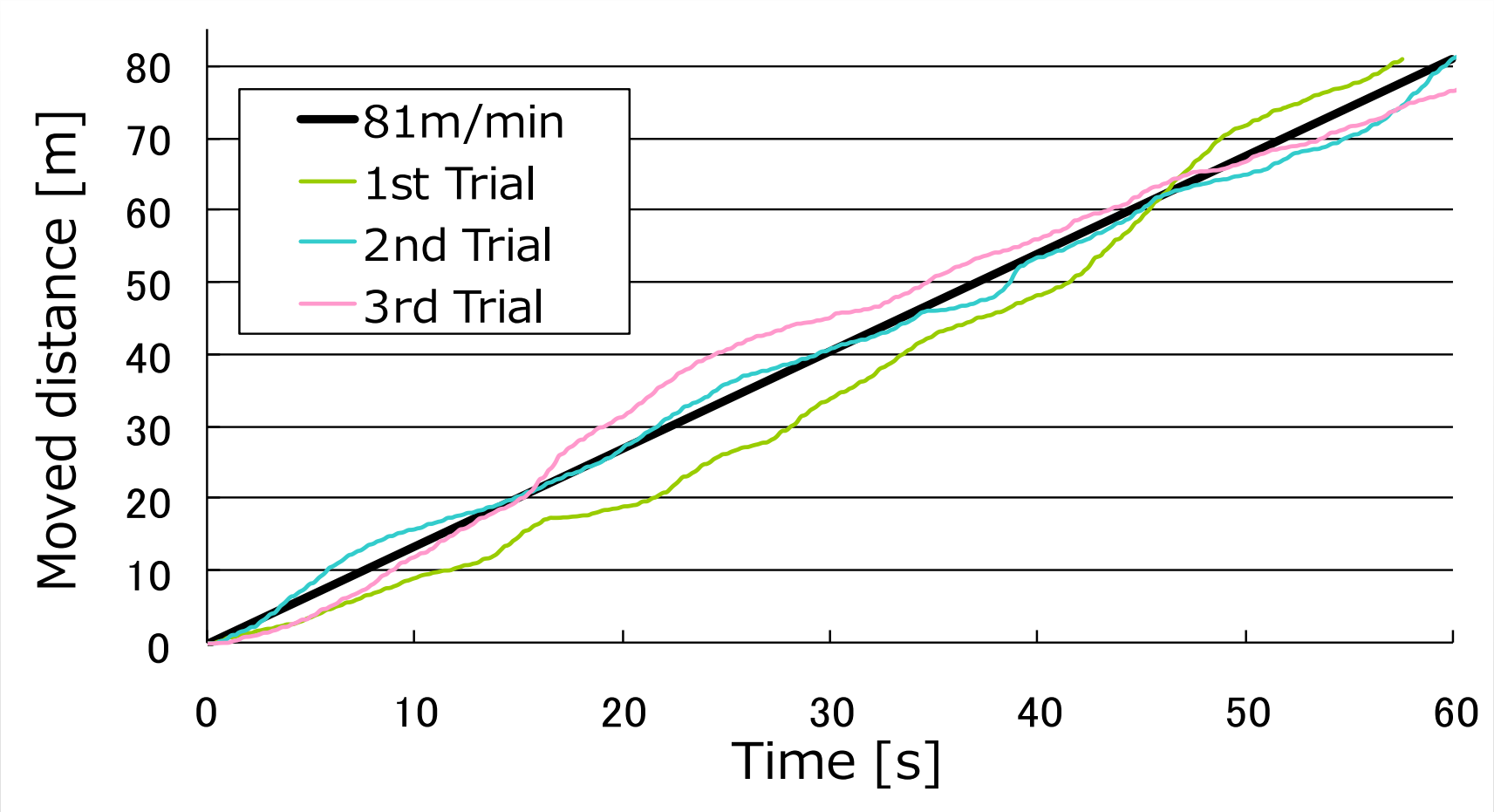




Experimental circuit for field trial:

- Exercise amount measurement using 3D acceleration sensor
- Composed of 3 main parts

Observed walking speed characteristics by using 3D acceleration sensor



- The result improves 3.3METs can be recognized for usual speed of walking

Confirmation of feasibility for the sensors

- Accurate simple ECG sensor by using Mixed-signal CPU
- Exercise amount sensor available for METs value estimation

Long-term operation
(order of month)

- Essential technical issues resulted for the sensors
  - Power consumption reduction
  - Decrease in size

Life-time expansion of the ECG sensor

- Actual power consumption of the experimental sensor without power saving control
  - LSI power consumption : 1.6mA$_{min}$
    (MSP430FG4616, operated 3.0V)
  - Capacity of coin cell : 280mAh (CR2430)

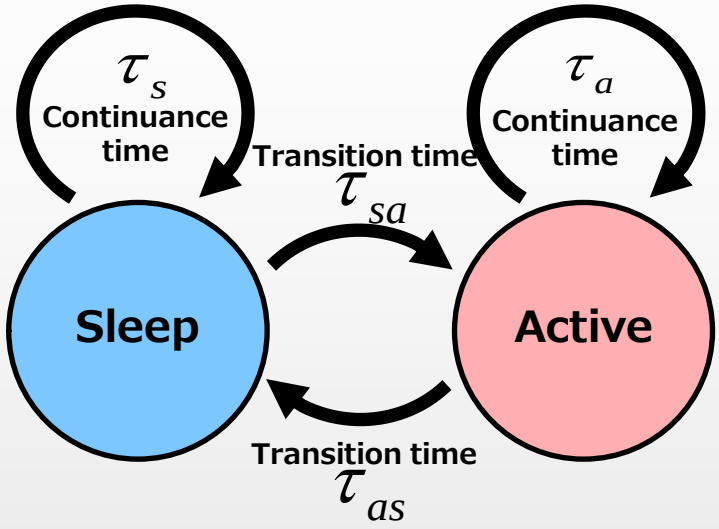
Life-time : about 1 week (175hours)

too short!!

Solution

Intermittent operation and control of sensor

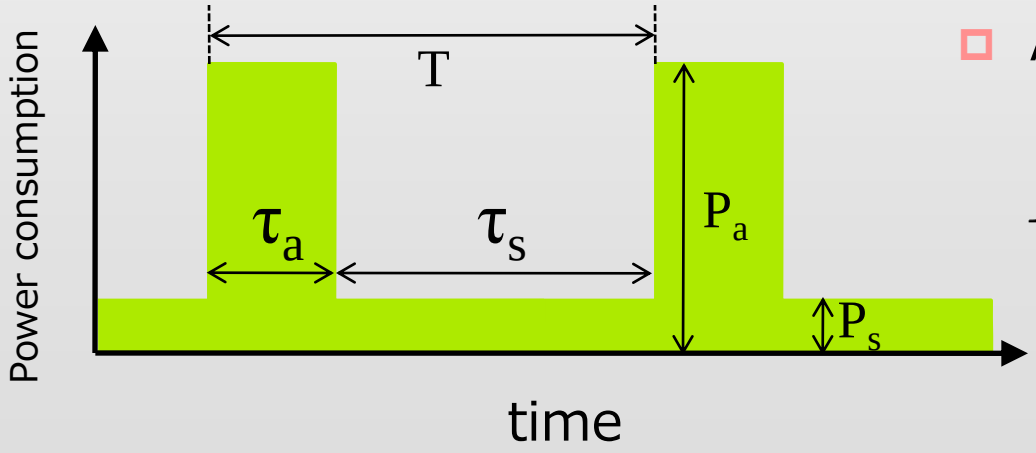
Intermittent operation control algorithm to reduce the ECG sensor power consumption



State transition of sensor activation operation

- Activated time ratio:

$$\eta_s = \frac{\tau_a}{\tau_a + \tau_s}$$



Reduction of average power consumption

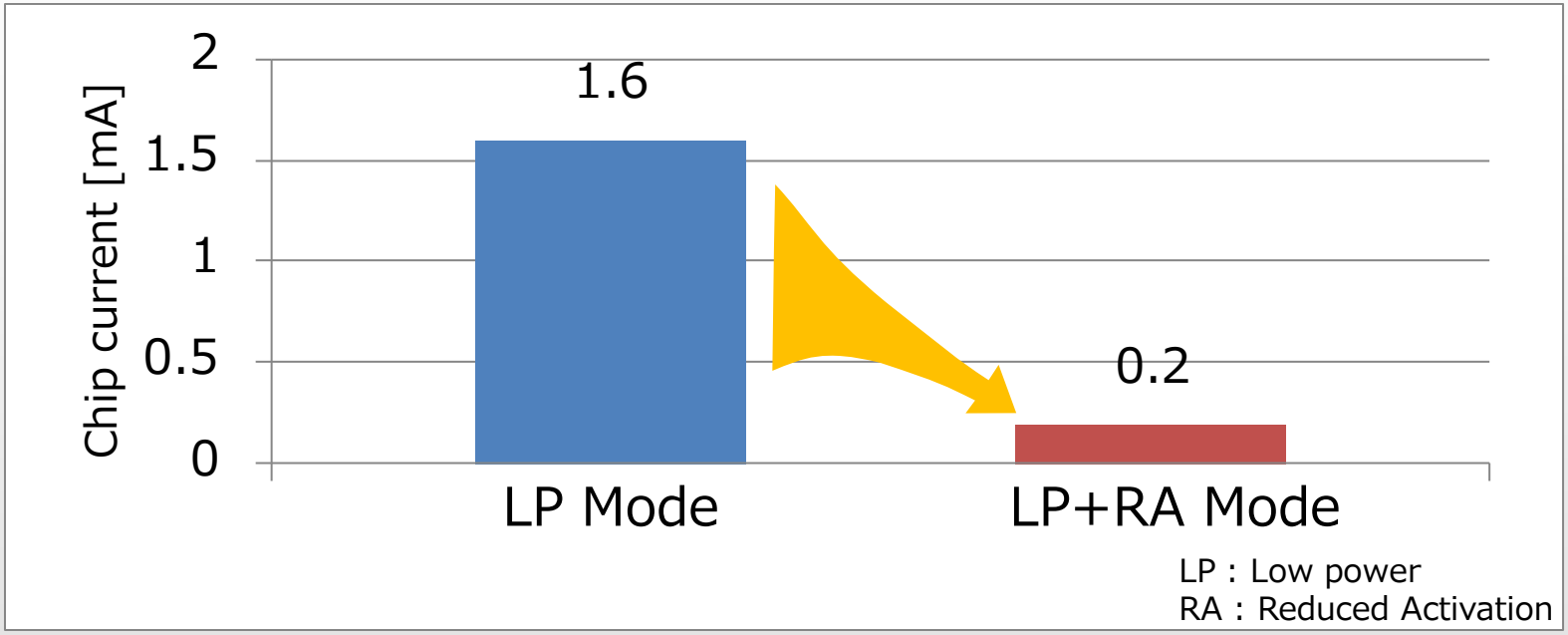
- Average power consumption :

$$P_d = \frac{\int P_a dt + \int P_s dt}{T}$$

Sleep time :τ_s is 1msec
Active time :τ_a is 0.6msec

Transition time:τ_{sa} and τ_{as} is less than 10nsec

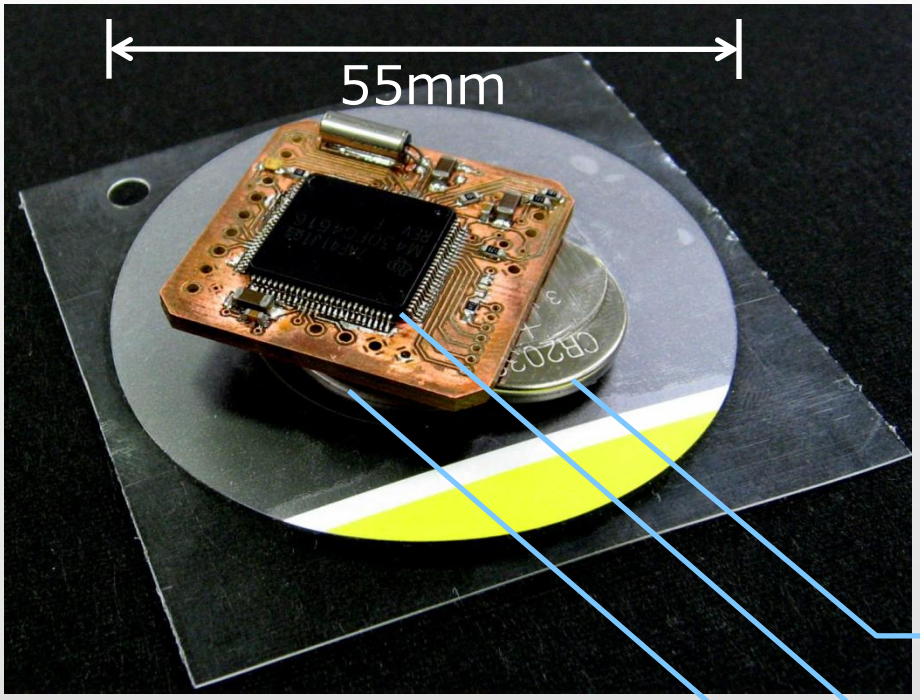
Power consumption reduction of ECG sensor (experimental result)



Life-time : about 2 months (1400hours)

ECG sensor

Implementation image



Sensor specification

Function	ECG
Main parts	MSP430 CR2032
Power consumption	200μA @2.2V
Size (diameter , thickness)	55mmΦ, 8mm
Weight	< 6g

Conclusions

- State of the art ECG sensor development
  - Life-time of the ECG sensor :
    2 months at least for the continuous operation
  - All the sensor components are mounted on 55mmΦ electrode
- Availability of synchronous measurement of ECG and exercise amount, can be applied to rehabilitation system for heart disease patients

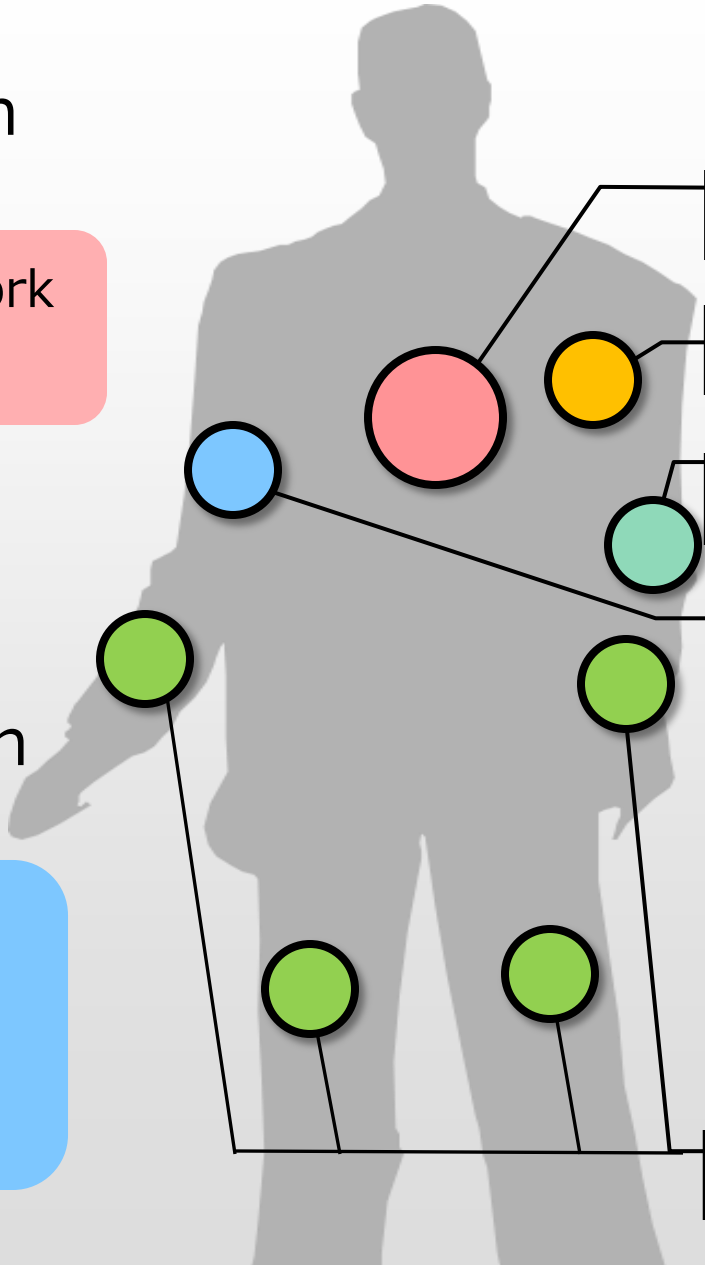
Recent issues to be studied

Communication technology

- Body Area Network
- Security

Implementation technology

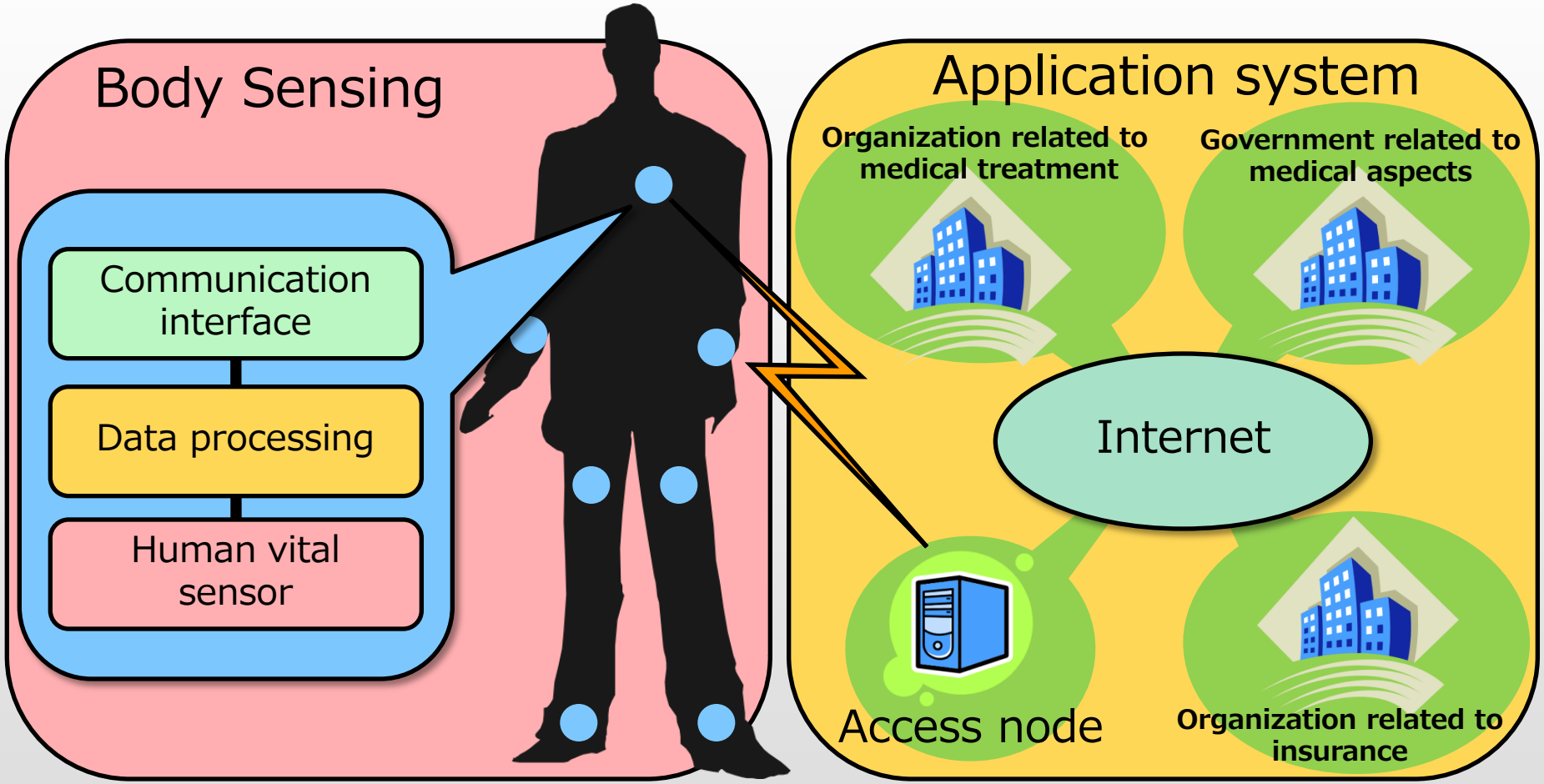
- Use of harmless materials for human body
- Small and thin sensors



Sensing technologies

- ECG sensor
- Temperature sensor
- Blood pressure sensor
- Blood oxygen saturation levels sensor
- 3D acceleration sensors

Application systems for the future



Thank you for your attention