

eHealth: Combining Health Telematics, Telemedicine, Biomedical Engineering and Bioinformatics to the Edge



eHealth Competence Center Regensburg
December 2~5, 2007

Estimation of Mental Stress Levels Based on Heart Rate Variability and Stress Factor in Mobile Settings



Lizawati Salahuddin^{\$}, Jaegel Cho^{*}, Chul-Ho Cho^{*}, Jong-Min Woo[&], Desok Kim^{\$}

^{\$}Mobile e-Health Research Group, Samsung-ICU Research Center, Information and Communications University, Daejeon, Korea



^{*}Telecommunication & Network R&D, Samsung Electronics, Suwon, Korea

[&]Dept. of NeuroPsychiatry and Stress Research Institute, Inje University Paik Hospital, Seoul, Korea



Outline

- 1. Motivation**
- 2. Methods and Subjects**
- 3. Experiments and Results**
- 4. Conclusions**
- 5. Discussions and Future Works**
- 6. Acknowledgement**

1. Motivation

1.1 Mental Stress

1.2 Stress Questionnaires

1.3 Heart Rate Variability (HRV)

1.4 Experimental Design

1.1 Mental Stress

- ◆ Our 'fight or flight' reaction to life threatening events.
- ◆ Chronic stress occurs when you deal with high emotional, mental and physical demands.
- ◆ Long term exposure to stress^{1,2}.
 - accelerates the progression of coronary artery disease
 - exacerbates the course of autoimmune disorders
 - increased risk of developing colds
- ◆ Important to manage stress levels.
 - Levels of stress-related hormones in the blood
 - Stress questionnaires
 - Recent patented methods using heartbeat detection : not validated using rigorous statistical tests.

¹. S.C. Segerstrom and G.E. Miller, "Psychological Stress and the Human Immune System: A Meta-Analytic Study of 30 Years of Inquiry", *Psychological Bulletin*, 2004

². B.S. McEwen, "Protective and Damaging Effects of Stress Mediators", *The New England Journal of Medicine* , 1998

A simplified version of Stress Response Inventory¹

¹Choi SM, Kang TY, Woo JM. Development and validation of a modified form of the stress response inventory for workers. J Korean Neuropsychiatr Assoc. 2006; 45(6): 541-53.

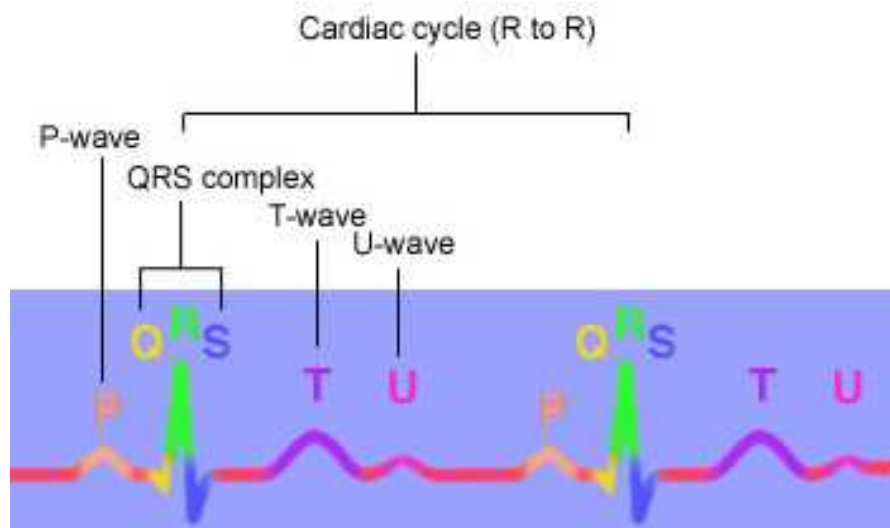
Stress Factors	Questions
Tension	My body trembles.
	I feel tense.
	My head hurts or it feels heavy.
Aggression	I act violently (such as reckless driving, cursing, fighting).
Somatization	I suffer from indigestion.
	My stomach hurts.
	I feel dizzy.
Anger	My voice is louder than it usually is.
	I easily get impatient.
Depression	I have lost my self-confidence.
	I have lost incentive to do anything.
	I have no future in my current work.
	I often stare blankly.
	I feel bored.
	I am useless (or unworthy).
	I don't like moving any part of my body.
Fatigue	I am easily fatigued.
	I feel totally exhausted.
Frustration	My chest feels tight.
	Everything bothers me.
	I feel on edge.
	My heart throbs.

1.2 Stress Questionnaires

- ◆ Inquire about stressful events and individual's reactions to stress
 - Perceived Stress Scale (PSS): the assessment of how unpredictable, uncontrollable, and overloaded a respondent perceives his or her life during the past one month.
- ◆ Inquire about stress related symptoms
 - Stress Response Inventory¹ (SRI) : consists of 39 items to score mental, emotional, and physical symptoms occurred during the previous two weeks.
 - seven stress factors: tension, aggression, somatization, anger, depression, fatigue, and frustration

¹K.B. Koh, J.K. Park, C.H. Kim, and S. Cho, "Development of the Stress Response Inventory and its application in clinical practice," Psychosomatic Medicine, 2001, vol. 63, pp. 668-678.

1.3 Heart Rate Variability (HRV)



- ◆ Autonomous Nervous System (ANS)
 - Sympathetic – Heart rate up
 - Parasympathetic– Heart rate down
 - Body functions regulated by two systems
- ◆ Heart Rate Variability (HRV) refers to the beat-to-beat alterations in heart rate.
 - High HRV : good adaptability of ANS
 - Low HRV : related to abnormal physiological condition & mental stress ^{1, 2}

¹ Am J Physiol Regul Integr Comp Physiol. 2002 May;282(5):R1333-41.

² International Journal of Cardiology 84 (2002) 1–14

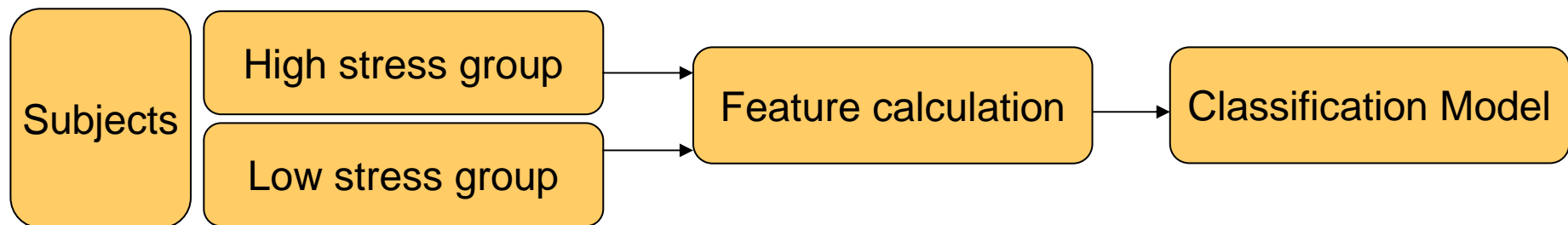
1.4 Experimental Design

◆ Purpose

- To establish a mathematical model of stress levels with multiple HRV features & the stress factor score.

◆ Background

- We have been investigating a stress management method as a mobile e-health application using mobile sensors and a mobile phone.



2. Subjects & Methods

2.1 Subjects

- 360 normal office workers in Seoul, Korea
- Came in the lab for regular annual check up
- between 9 AM and noon
- Asked to fill out the **SRI** first.

Age	Gender		Total
	<i>Female</i>	<i>Male</i>	
20-29	72	33	105
30-39	43	80	123
40-49	45	45	90
50-69	22	20	42
Total	182	178	360

2.2 Measurements

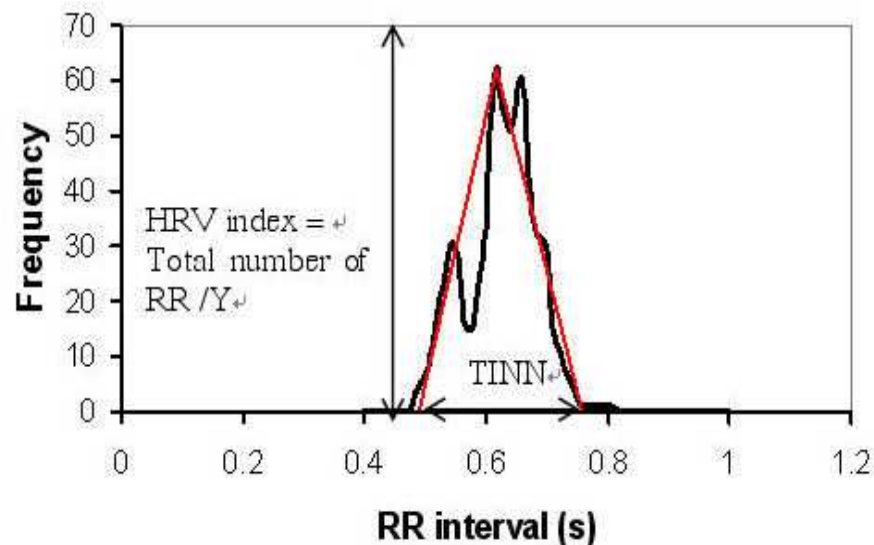
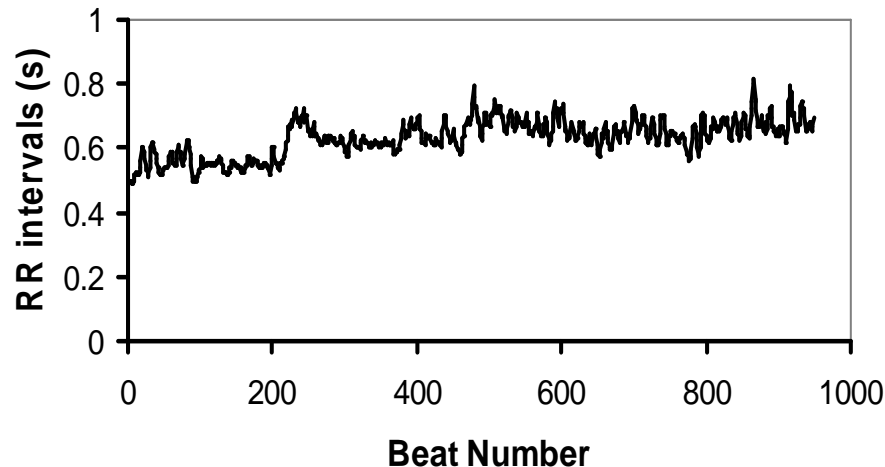


Photoplethysmography (PPG) sensor (Freeze-Framer)



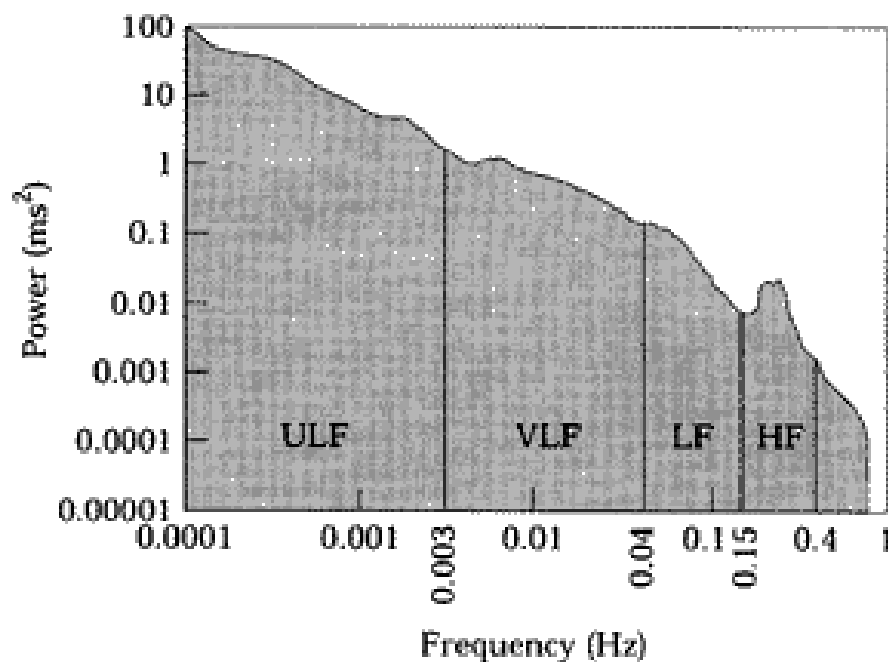
- ◆ Height, weight, body fat content, body temperature, blood pressure, and blood glucose levels
- ◆ Three minute long data of heartbeats were then recorded right after the 5 min resting stage.
- ◆ Finger photoplethysmography (PPG) sensor (Freeze-Framer®, Institute of HeartMath LLC, Boulder Creek, CA).

Calculation of the HRV features



- ◆ Mean heart rate (HR), Mean RR intervals
- ◆ Standard deviation of RR interval (SDNN)
- ◆ Coefficient of variation of RR interval (CV)
- ◆ Root mean squares of successive differences (RMSSD)
- ◆ % differences in successive RR intervals greater than 50 msec (PNN50)
- ◆ HRV index (HRV Index, bin width of 8.0 ms),
- ◆ Width from triangular interpolation of heartbeat interval histogram (TINN), and
- ◆ Stress index (SI)

Calculation of the HRV features



- ◆ low frequency (LF),
- ◆ high frequency (HF),
- ◆ the ratio of LF to HF (LF/HF),
- ◆ normalized LF (LFnu), and
- ◆ normalized HF (HFnu)

Data Analysis

- ◆ Subjects were divided into two groups: low (n=236) and high stress group (n=124)
 - using k-means clustering analysis
 - with six stress factor scores as the variables
 - excluding the one to be used in the stress formula.
- ◆ Stress formula was calculated by using logistic regression analysis.
 - Anger factor score, physiological measures, and HRV features
 - Five fold cross validation

3. Results

Significant Features that Distinguish High vs. Low Groups (ANCOVA with age covariance, $p < 0.05$)

Measures	Low stress group (n=236)	High stress group (n=164)
Body Temperature	36.36 \pm 0.352	36.43 \pm 0.629
Systolic blood pressure	120.0 \pm 14.12	115.5 \pm 13.39
Glucose level	98.38 \pm 17.20	91.70 \pm 12.10
LF/HF	1.751 \pm 1.715	1.862 \pm 1.526
LFnu	53.43 \pm 18.74	56.94 \pm 16.94
HFnu	45.82 \pm 18.93	42.31 \pm 17.15

Salahuddin L, Jeong MG, Kim D, Lim SK, Kim W, Woo JM. Dependence of heart rate variability on stress factors of stress response inventory. Healthcom 2007; 2007 Jun 19-22; Taipei, Taiwan; p. 236-239

3. Results

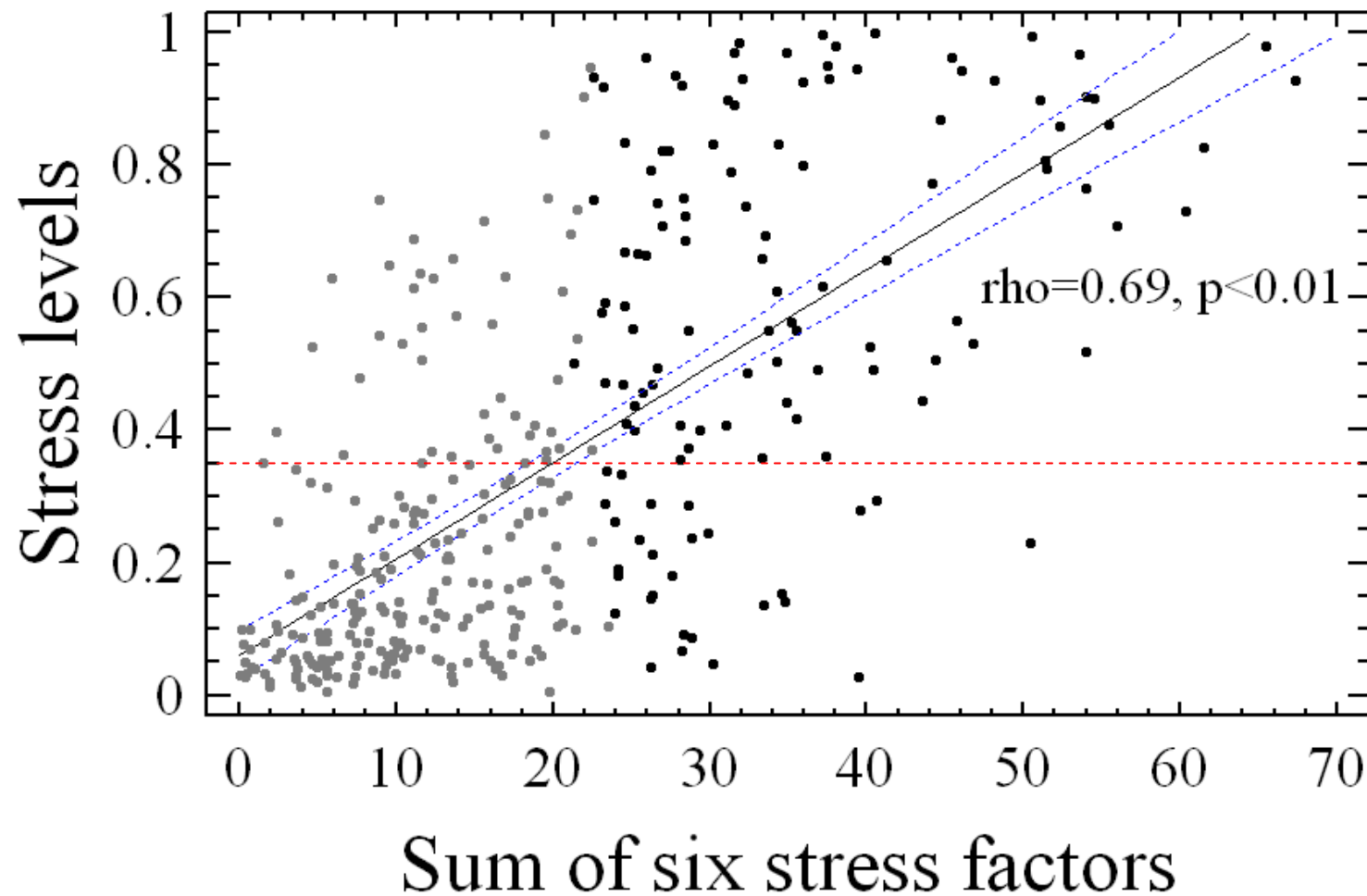
◆ Stress formula

$$\text{Stress } (\eta) = \exp(\eta) / (1 + \exp(\eta))$$

where $\eta = -1.00 - 2.19 \cdot \text{Mean RR} + 4.86 \cdot \text{SDNN} - 4.77 \cdot \text{CV} + 0.64 \cdot \text{PNN50} - 0.94 \cdot \text{SI} - 1.05 \cdot \text{HF} + 1.64 \cdot \text{Anger factor}$

Classification Table

Actual Class	Group Size	Predicted Class	
		Low Stress	High Stress
Low Stress	43	35 (81.4%)	8 (18.6%)
High Stress	29	6 (20.7%)	23 (79.3%)



Stress levels estimated by the stress formula were significantly correlated ($\rho=0.69$, $p<0.01$) with the sum of six stress factor scores in both low (gray disks) and high stress group (dark disks).

4. Conclusions

- ◆ Our stress formula was based on the annotation of stress groups by stress questionnaire scores.
- ◆ Our stress formula will provide a continuous monitoring of one's stress levels.
 - Conventional questionnaires are inconvenient & cannot be used frequently due to the reliance of the events occurred previous several weeks.
- ◆ Our stress formula showed approximately 80% accuracy of predicting which stress group a normal subject belongs to.

5. Discussion and Future Works

- ◆ A mobile device that consists of an ECG sensor, a mobile phone, and analysis software could be used for the individual stress assessment anywhere and anytime.
- ◆ On going & future works:
 - Short term measurement for reliable HRV analysis
 - Long term (circadian, seasonal) variation of HRV features
 - Clinical studies including well defined stress groups

Mobile Health Monitoring Platform

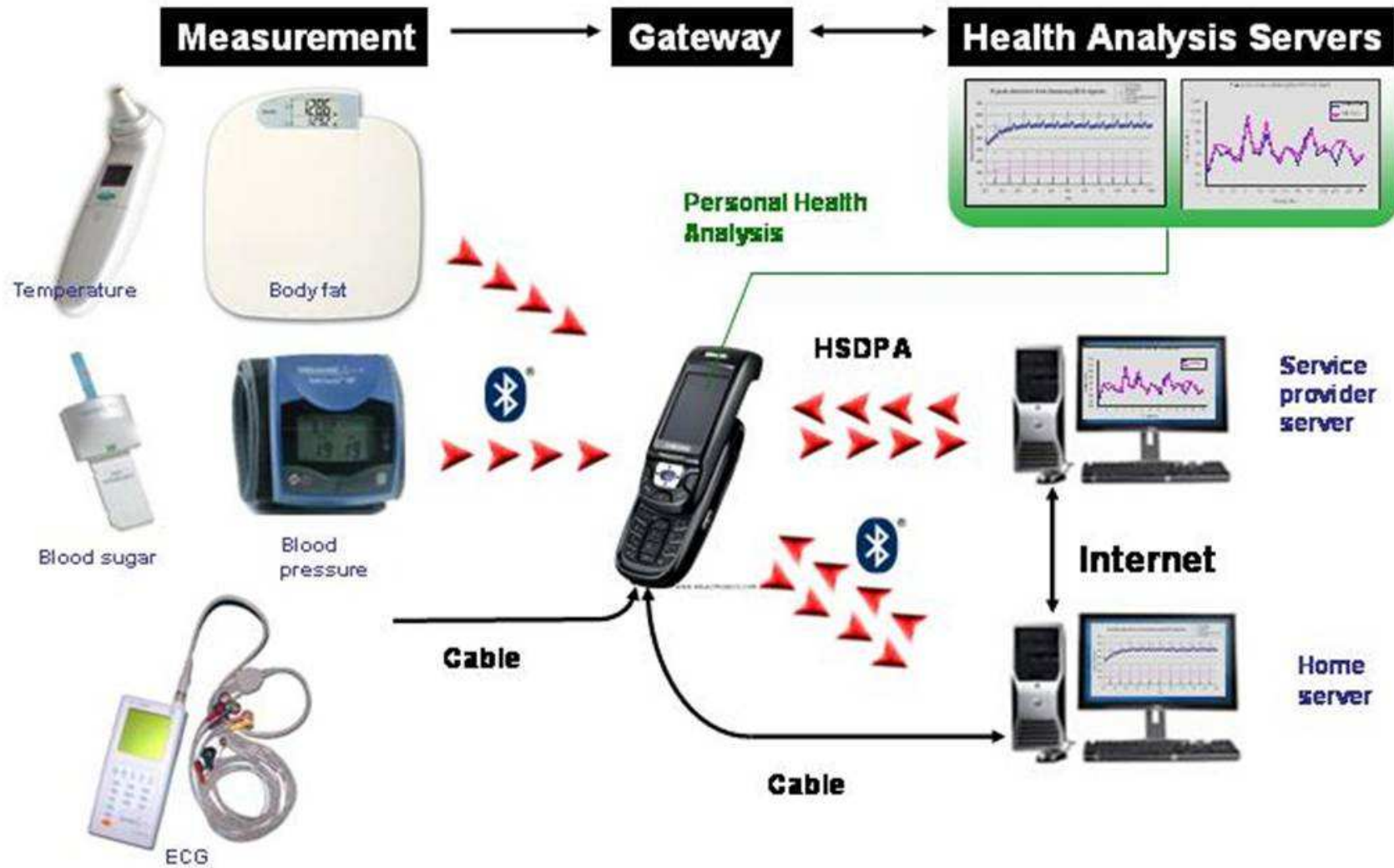


Image courtesy from Bluetooth, Card Guard, Tanita, & Samsung Electronics

6. Acknowledgement

- ◆ Suntae Jung, PhD at Samsung Electronics, Inc., Suwon, Korea
- ◆ Rollin McCraty, PhD at Institute of HeartMath, Boulder Creek, CA