WEARABLE HUMAN EMOTION MONITORING SYSTEMS

23 September 2019

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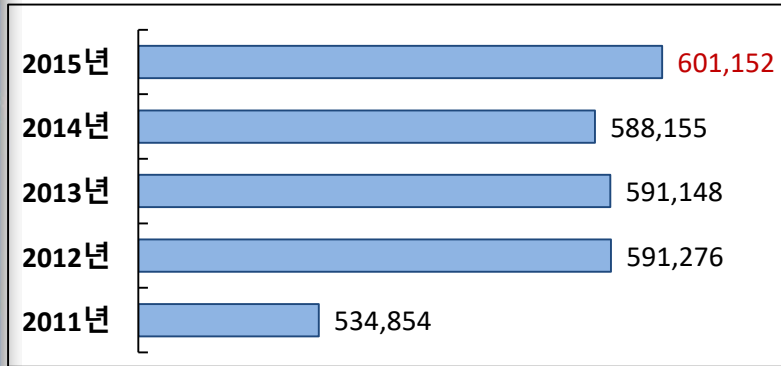
Cell bench Research Center

KAIST

E.T.

THE EXTRA-TERRESTRIAL

UNIVERSAL

Mental Health and Human Emotion

Domestic **Depressive Disorder** (persons)

Year	Persons
2015년	601,152
2014년	588,155
2013년	591,148
2012년	591,276
2011년	534,854

[Health Insurance, 2015]

OECD **Suicide Rate** (persons)

Per 100, 000 persons

28.7

OECD Ave. 12.0

Korea	Japan	Fin.	Pol.	Austria	Swed	Swiss	Nor	Den	Ger	Neth	Spain	Italy	Turkey
28.7	18.7	15.8	15.3	13.6	12.3	12.0	11.3	10.8	10.8	10.5	7.5	6.3	2.6
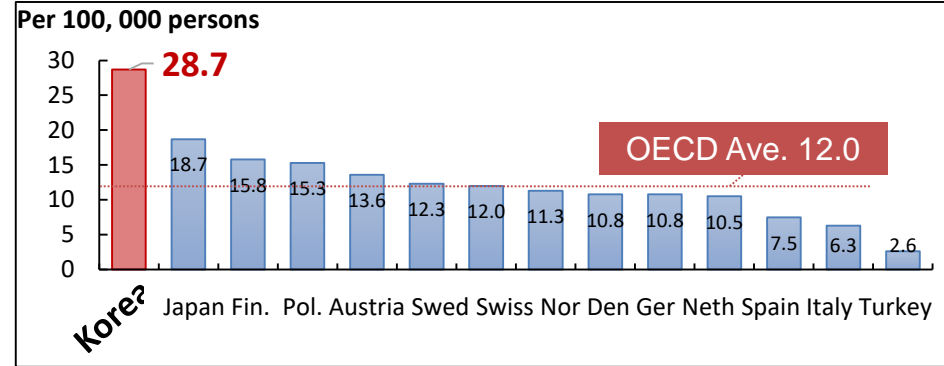
[OECD.STAT, Health Status Data, Statistics and Indicators for 34 Countries, 2012*,2013]

Domestic **Accidental Crime** Ratio
(over total crime, %)

Violence	Assault	Homicide	Theft	Rape	Robbery	Fraud
42.5	35.3	29.8	28.1	27.2	16.8	1.4
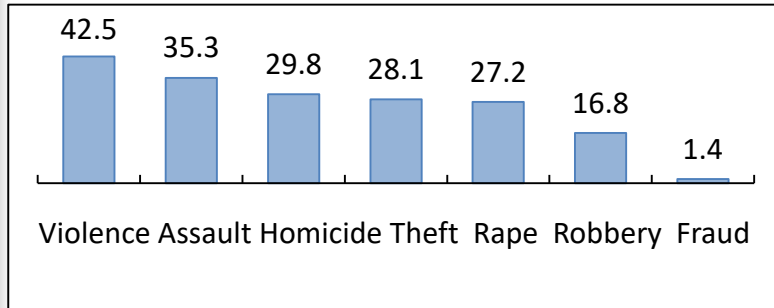
[Police, 2015]

Domestic **Mental illness and Socio-economic Loss**
(Youth Puberty/Misconduct, Elderly/Menopause Climacteric, etc.)

Mental Illness Experience [보건복지부 2012년]	**Socio-economic Loss** [삼성경제연구소, 2013]
1 out of 4 **(27.6 %)**	20.066 Trillion Won

Monitoring of the Physiological Signs of Human **Mental Health and Emotional Status**

Human Status

Output (Results)

Brain Mind
(Reason, **Emotion**: Experience, Memory, etc.)

Human Status
- Physical (Body)
- **Mental (Mind)**

Input (Cause)

Body Sensory
(5 Senses)

Environmental Situation and Conditions

Functions & Mechanisms
Input-Output Process and Causality Analysis

Signs & Symptoms
Output Monitoring and Assessment (Physiological Signs of Psychological Symptoms)

Human Emotion Monitoring Patches

Non-invasive and **Active** Monitoring of
Human **Mental Health** and **Emotional Status**
based on the **Physiological Signs on Human Skin**

Environmental Situations and Conditions

Emotions

**Emotion Bands
(Multi-Emotions)**

감정 Profiler

Thermal Comfort Patch

Psychological Stress Patch

Emotional Touch Patch

Skin

**Physiological signs
- Temp. Sweat, Pulsewave, etc.)**

**Emotion Patches
(Mono-Emotion)**

Emotion Evaluator

Non-invasive Active Devices

Sensors

Actuators
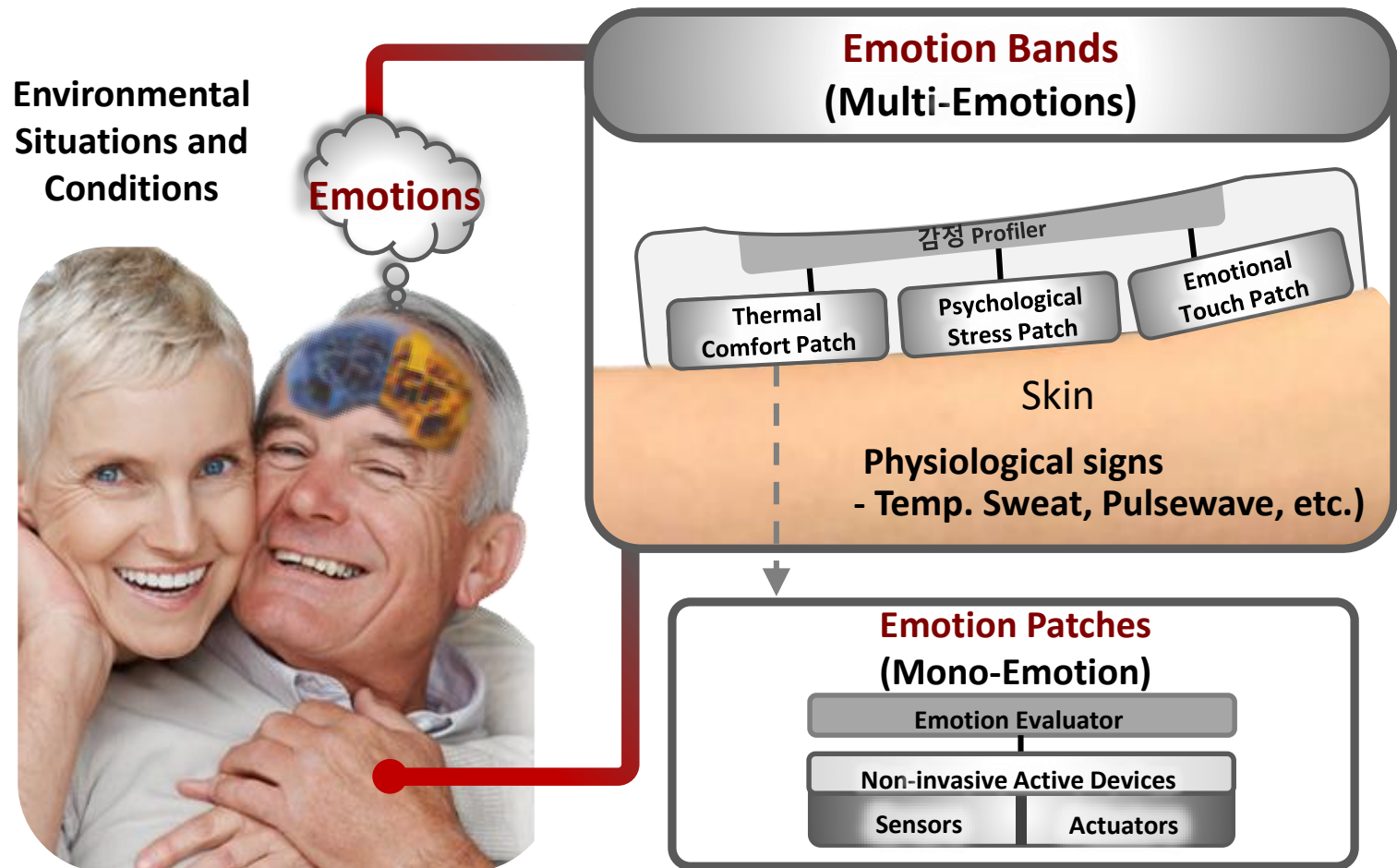
Skin Patches for Human Mental Health & Emotion Monitoring
(Physiological Signs on Human Skin)

Device Issues:
- **Stability (Reliable Detection)**
- **Comfort (Conformal Contact, Skin Trouble)**

I. Thermal Comfort
II. Emotional Touch
III. Physiological Stress

I. Thermal Comfort

19°C (66.2°F)?
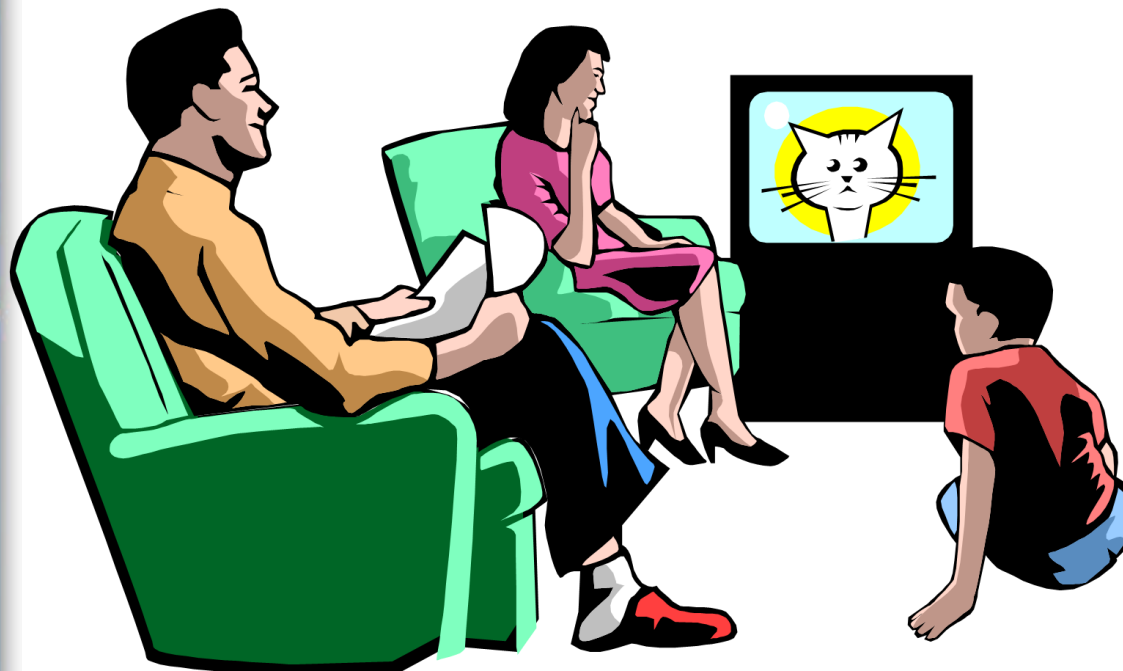
Environment ➡ Human Monitoring

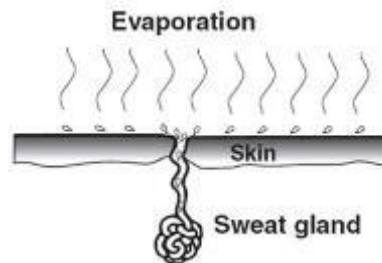# Sweat Rate:
A Skin Sign of Human Thermal Status

◈ **What is "Sweat rate"?**

▪ Quantitative change of human sweat amount
= Sweat mass generation / skin area / time [g/m^2h]

◈ **Physiological Meaning**

▪ Key indicator for human thermoregulatory response [4]

Evaporation

Skin

Sweat gland

▪ Linear with human core temperature [5]

Sweat rate

Human thermal status
(Core temperature)
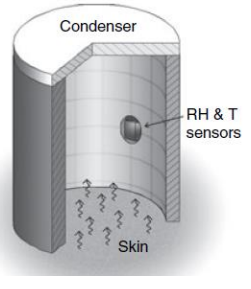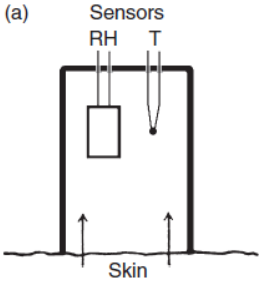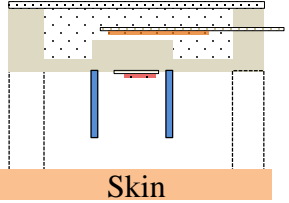
[4] K. Wilike, *et. al.*, *Int. J. Cosmet. Sci.* (2007)
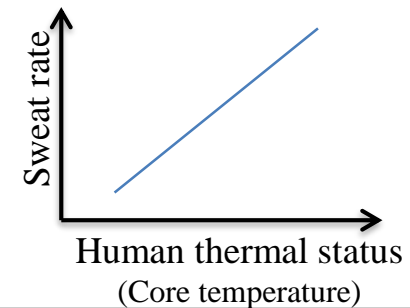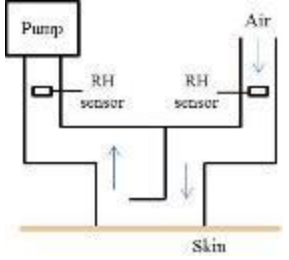
[5] Samual N. C., *et. al.*, *J. Appl. Physiol.* (2009)

☞ **Sweat rate indicates**
human thermoregulatory status objectively and quantitatively.

Ventilated Sweat Rate Measurement

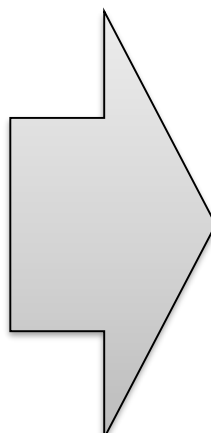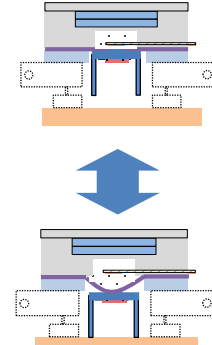| Type	Forced Ventilation		Natural Ventilation	
Device Structure [reference]	[Pietro S. et. al (2010)]	[Toshio O. et. al (1998)]	[Robert I. et. al (2009)]	Skin **Present (2015)**
RH ventilation method	Forced ventilation by pump	Forced ventilation by ice condenser	Natural ventilation **(Manual)**	Natural ventilation **(Automatic)**
Detection principle	RH* difference at two points	RH difference at two points	RH rising rate	RH rising rate
Portable (Weight)	N/A (Pump)	~ 1 kg (Condenser)	150 g	**63 g**
Stable (Continuous measurement)	◯	△ (Periodic ice removal)	△ (Manual initiation)	◯
Measurement period	N/A	N/A	2~3 min	**3 min**
Sweat rate range (g/m²h)	~ 600	~ 250	~ 200	**> 135**

*RH: Relative Humidity (%)

Sweat Rate Monitoring Watch

Portable Sweat Rate Monitoring

integrated with thermo-pneumatic actuators for automatic ventilation

Previous	Problems		Present	Solutions
Forced ventilation devices	Bulky size (~ 1 kg)			**Portable size (33 g)**
Natural ventilation devices	Manual ventilation Unstable to motion and external wind (< 0.5 m/s*)			**Automatic ventilation** **Stable to motion and external wind (~1.5 m/s**)**

* Environmental microclimate   ** Human walking speed

Cognitive Air-conditioning,
Human thermoregulatory status monitoring wrest watches, etc.

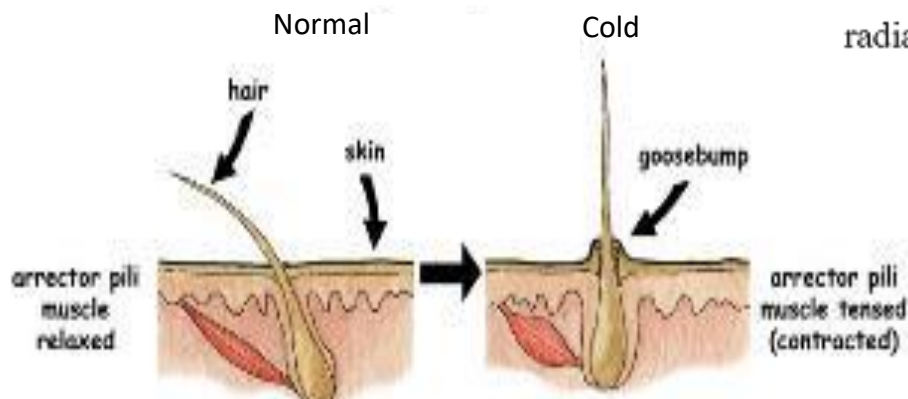👉 **Integrated Sweat Sensors for sweat rates, humidity, pH and ions.**

Skin Hardness Patches

Problems

- **Conventional physiological signs:**
  - **Skin temperature and conductance**
  - ➡ **Low accuracy: $R^2 < 0.7$**
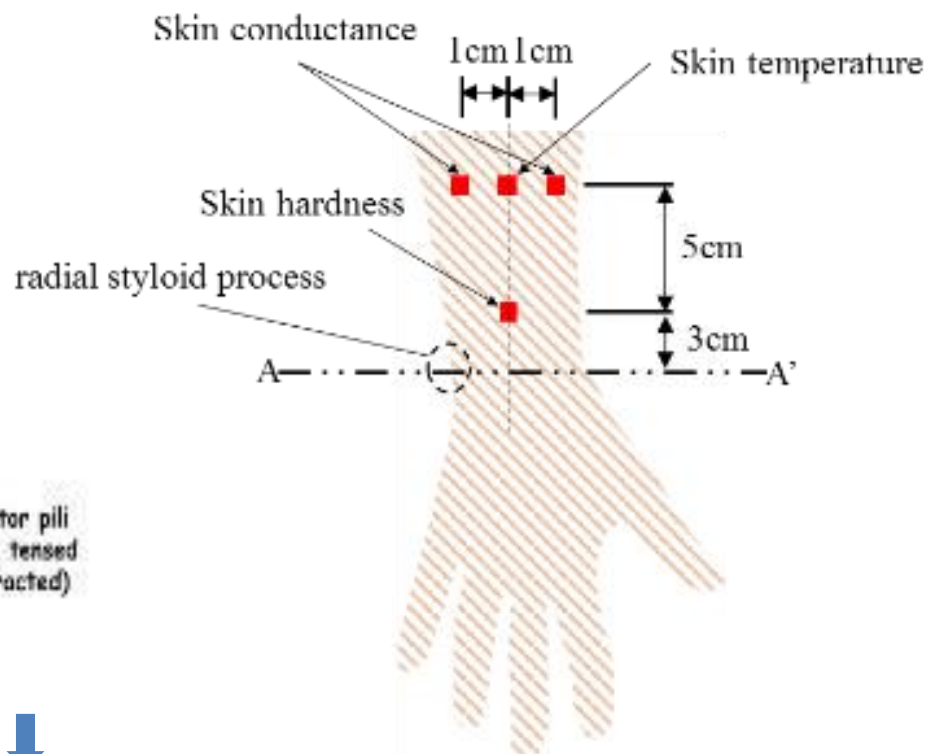
Physiological sign measurement

Solution

- **New physiological sign: Skin hardness**

Normal   Cold
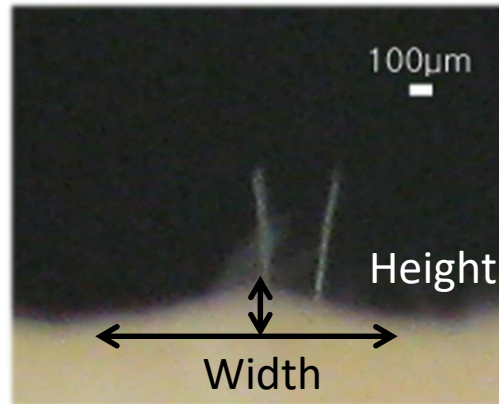

Accuracy: 17.4% ⬆   Error: 23.5% ⬇

II. Human Emotional Touch

Piloerection
(Goose Bumps)

Goose Bump Detection Patches

100μm

Height

Width

Goose bumps

Width	~2 mm
Height	~200 μm
Density	>10/cm²
Shape	Circular

Mosquito Repellent coils

(2 cm X 2 cm)

A ___ A'

B'

B

280
200
100
0
(μm)
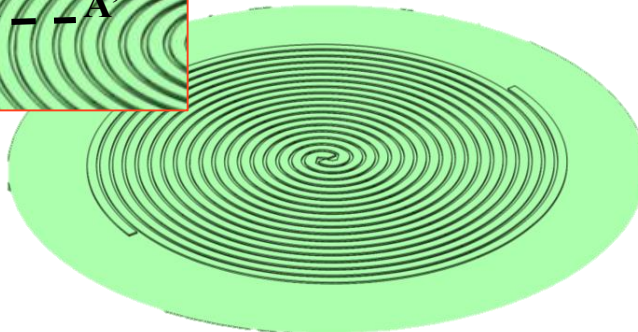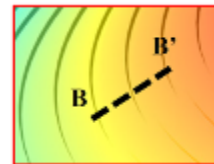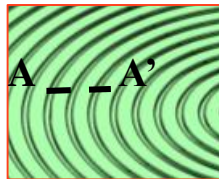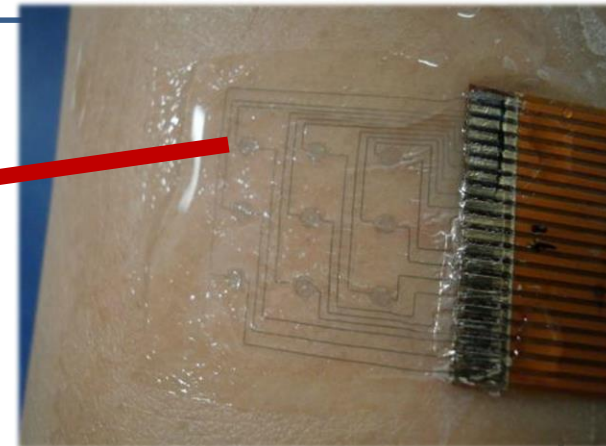
Surface Deformation ➜ **Capacitance decrease**
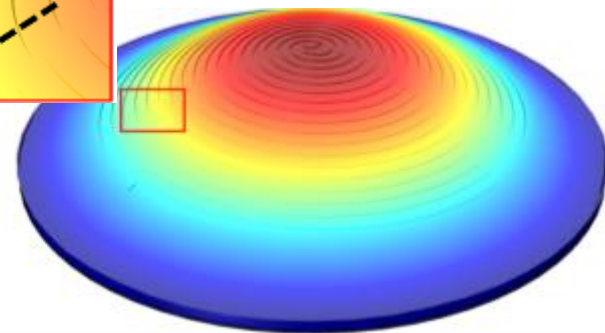
Goose Bump Monitoring Patch

Attachable and Detachable Skin Patch

(2 cm X 2 cm)
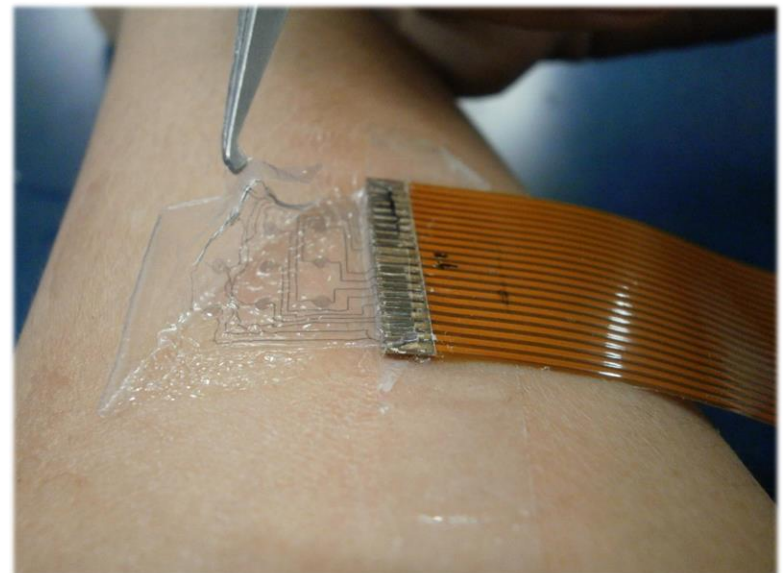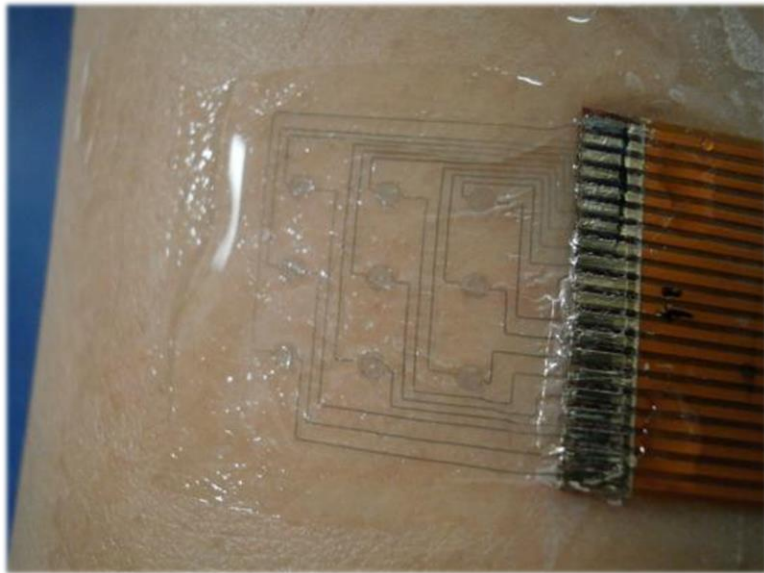
- Conformal skin contact (Van der Waals force)
- Easy removal (peeling off)

Goose Bump Monitoring

❖ **Two successive piloerection measurement**
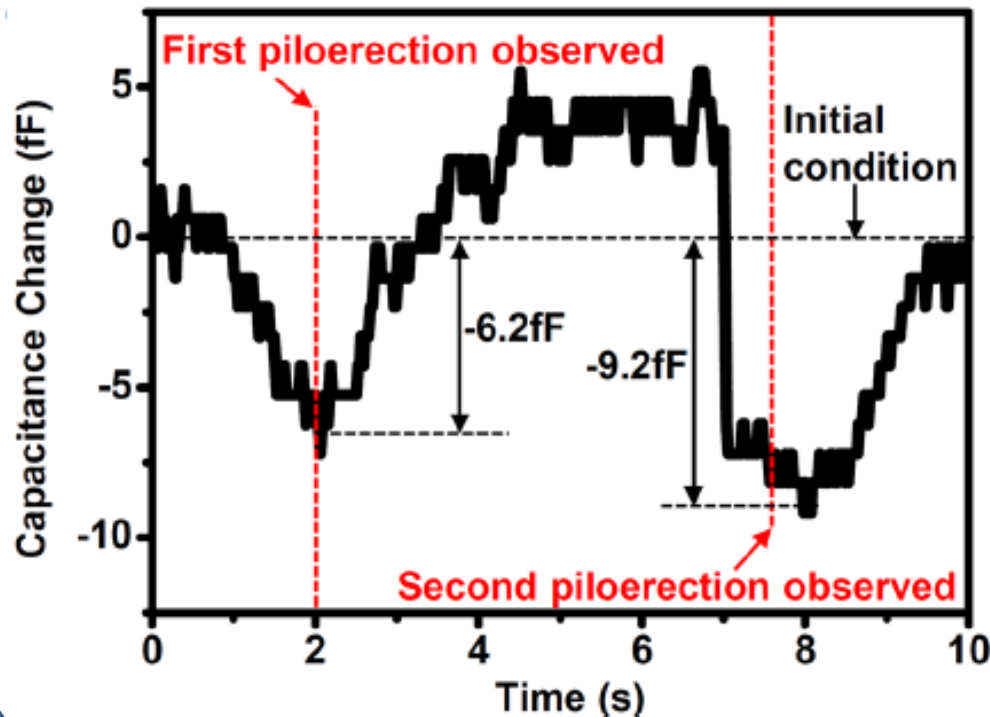
Subject	1 (male, age : 28)
Condition	Grabbing ice cubes

	Piloerection 1	Piloerection 2
Intensity	-6.2fF (~145μm)	-9.2fF (~194μm)
Duration	3.5s	3.5s

- Quantitative piloerection monitoring was demonstrated

TIME

These Goosebump Sensors Can Read Your Emotions

Alexandra Sifferlin @acsifferlin
June 25, 2014

Sounds crazy right? Read on

South Korean researchers are developing a technology that can measure your goosebumps—which are activated when you're cold, sure, but also when you're scared, moved or otherwise emotionally aroused. It sounds weird until you consider the potential applications for such a thing, some of which are fascinating while others seem unsettling when it comes to emotional privacy.

reachers are interested in, and companies like [...] data video-mining," which uses video cameras th[...] mood shoppers as they pass through a given stor[...]

But what can goosebumps tell us? The obvious r[...] biological method to combat chills. Goosebumps [...] each of our hairs contract, and the areas surroun[...] with a lot of fur, this retains heat. We don't have [...] the same purpose for us—but it does clue us into [...] uncomfortable level.

When it comes to getting goosebumps while wat[...] little more evolutionarily confusing, but research[...]

NEWS

≡ Sections

Technology

Goosebump sensor developed by Korean research team

By Leo Kelion
Technology desk editor

🕓 25 June 2014 | Technology

Newsweek ⊕ 🔍

The Goosebump Sensor That Knows How You Feel

BY **ANDREW RIDGWAY** / JULY 27, 2014 11:48 AM EDT

EVERJEAN VIA FLICKR
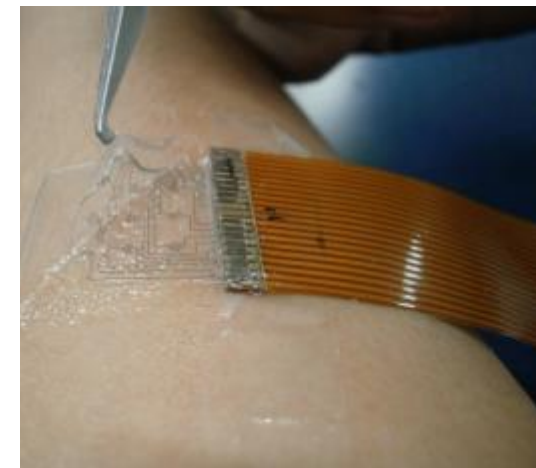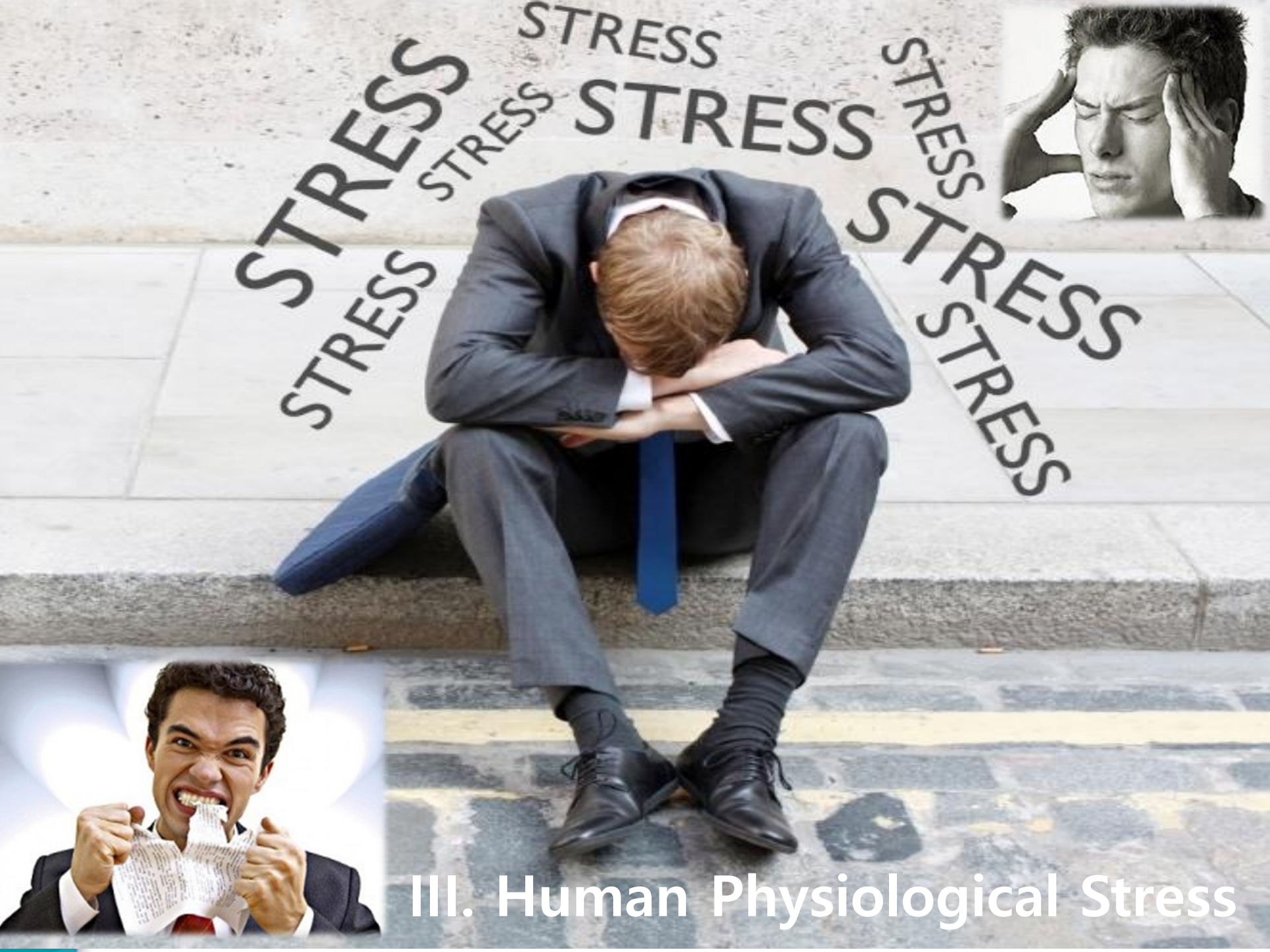
III. Human Physiological Stress

Human Physiological Stress

Negative influences of stress

Stressor

Acute stimulation

Chronic stimulation

Stress Out

Physiological Response Occur [1]

**Youth Puberty Misconduct
Elderly Menopause Climacteric**

- **Social problems**

**Suicide
Accidental Crime** [2]

**Decrease
work efficiency** [3]

- **Healthcare problems**

**Depressive
Disorder** [2]

**Cardiovascular
Illness** [4]

Stress monitoring (Mental heath management) in daily life

[1] Carlson, N., *Foundation of Physiological Psychology,* Pearson Education Asia, 2008.
[2] Mann, J., et al., *European Psychia*try, 2010.
[3] Macan, T., et al., *Journal of Educational psychology*, 1990.
[4] Pickering, T., et al., *Current hypertension reports*, 2001.

Stress Measurement Methods

Self report [5]
- Survey about subject's emotional state
- **No consistency**

Body fluid analysis [6]
- Measure cortisol concentration in saliva or blood
- **No continuous monitoring**

Physiological data analysis from multiple sensors [7]
- Measure fight-or-flight response of sympathetic nervous system
- **Objective, Quantitative, and continuous monitoring**

[5] Horowitz, M., et al., *Psychosomatic medicine*, 1979.
[6] Lee, J., et al., *Medical Hypotheses*, 2012.
[7] Healey, J., et al., *IEEE TRANSACTIONS ON INTEK|LLIGENT TRANSPORTATION SYSTEMS*, 2005.

Stress Signs (Measurands)

❖ Physiological stress responses

Pupils dilate   Salivary cortisol increases

Quick and deep breathing

Heart beats faster

Blood pressure increases

Muscles become more tense

Skin:
blood vessels constrict;
chills and sweating

(Pulsewave)   (Sweat)   (Temperature)

Typical physiological skin signs for stress monitoring

A. Pulse wave
B. Skin conductance
C. Skin temperature

❖ Response to stress

Type of stress \ Measurands	Pulse wave (HRV[†])	Skin conductance	Skin temperature
Acute stress[††]	N/A	Phasic response amplitude↑[15]	-
Chronic stress[†††]	$\frac{LF}{HF}$↑[1]	Tonic level↑[15] frequency↑[15]	Tonic level↓[16]
Stress vulnerability	$\frac{LF}{HF}$↑[14]	N/A	N/A

† Heart rate Variability(HRV):
  Spectral analysis of p-p interval of pulse wave
† † Acute stress: response within 1~3 second[n]
† † † Chronic stress: stress which are not acute stress

[1] Carlson, N., *Foundation of Physiological Psychology,* Pearson Education Asia, 2008.
[13] Porges, S., *Neuroscience and Biobehavioral Reviews*, 1995.
[14] Cacioppo, J., et al., *Handbook of psychophysiology*, Cambridge, New York (2007) Chap.8.
[15] Kreibig, S., et al., *Psychophysiology*, 2007.

Three-Layer Patch Structure

Skin conductance sensor
(Electrodes)

Skin temperature Sensor
(RTD Electrodes)

25x15x0.07 mm³

1st layer
- **Skin contact layer**

2nd layer
- Insulation layer
(Parylene C)
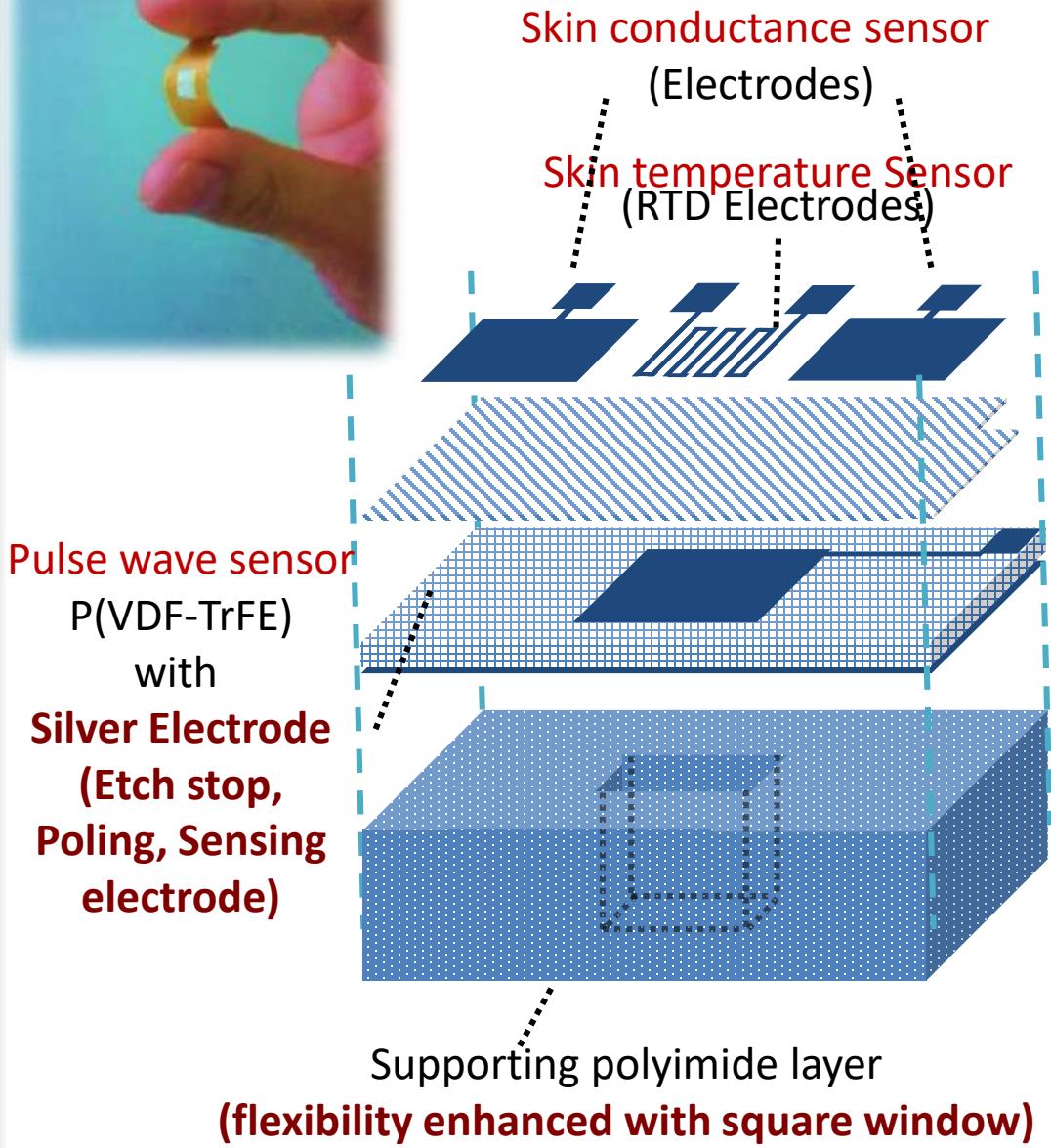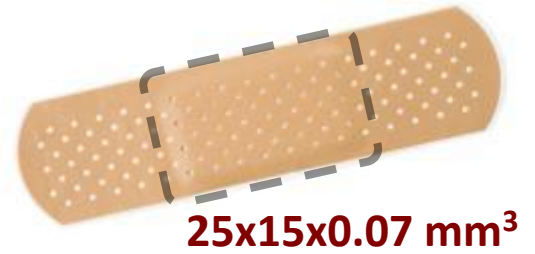
Pulse wave sensor
P(VDF-TrFE)
with
**Silver Electrode
(Etch stop,
Poling, Sensing
electrode)**

3rd layer
- **Pulse wave sensor layer**

Supporting polyimide layer
(flexibility enhanced with square window)

Stress Monitoring Patches
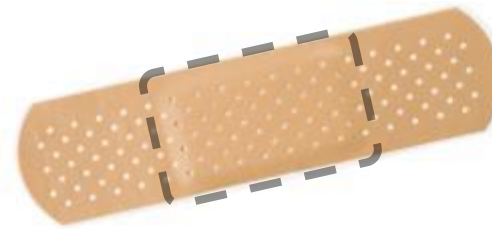
25x15x0.07 mm^3

- Integrated Multiple Sensors
  - Skin contact area (371mm^2): 1/125(0.8%) of the conventional device

- Window Fabrication Process:
  - Flexible patches

☞ **Headsets, Wrist/Arm/Hair Bands, Wrist Watches, Goggles/Glasses, etc.**

Human Mono-Emotion Patches

Stress Management

Arts Likeability

Smart Air-conditioning

Emotion Patch

Impression

Stress

Thermal Status

Skin Temp.

Goose Bump

Heart Beat

Emotion

Sweat

Blood Flow
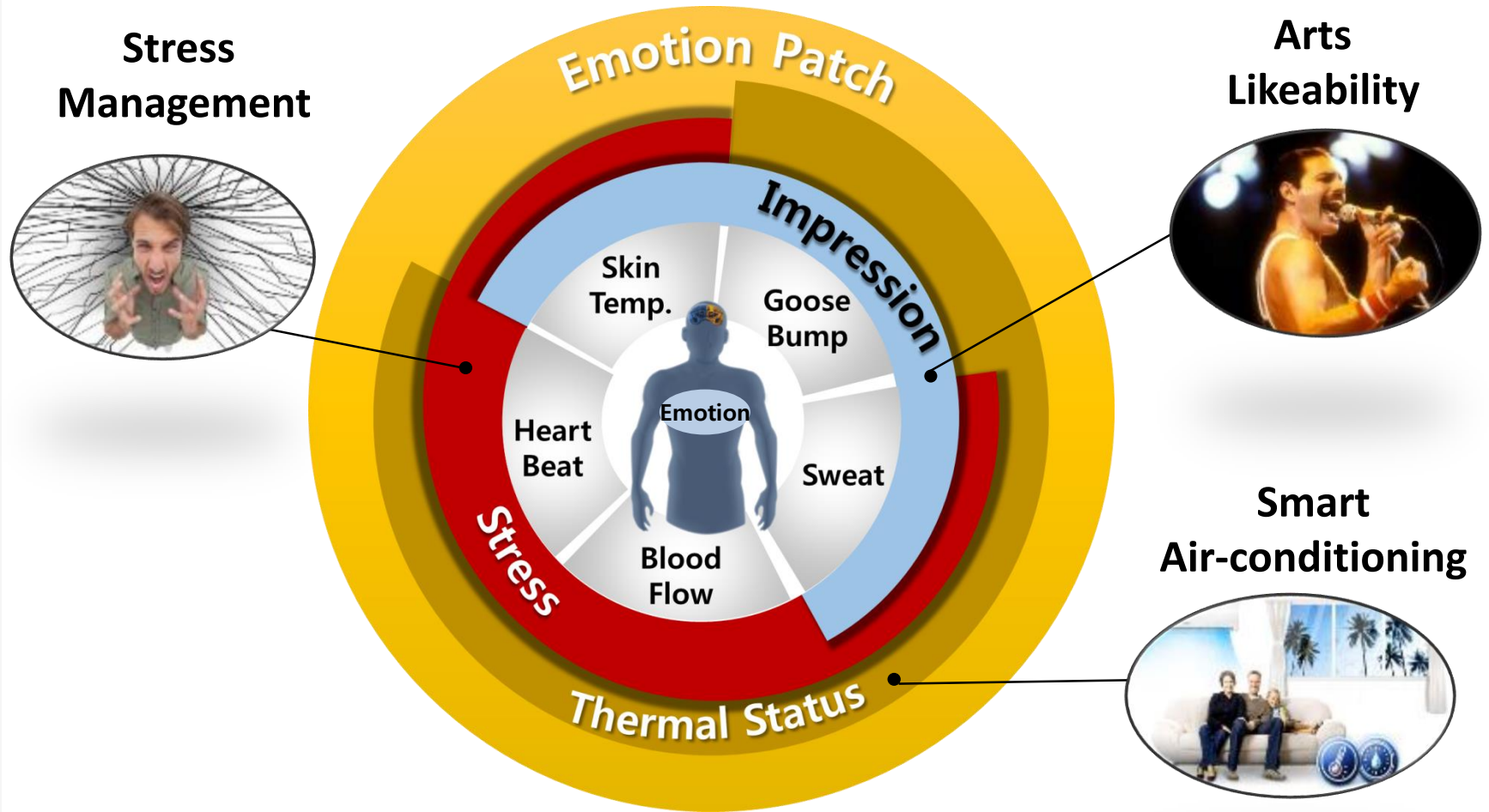
Wearable Product Industry

SAMSUNG 삼성전자 LG전자 (intel)   Microsoft PHILIPS

Korea-U.S.A Collaboration Activity on N/MEMS and Circulating Tumor Cells

Activity	Since	Count	Institutions
Annual Symposium	2003	15 (1,260 Attendees)	KAIST(8), USB(5), UCSD(2)
MOU	2003	7	UCB(4), UCSD(3)
Research Projects	2004	8	UCB(2), UCSD(3), U Michigan(3)
Researcher Exchange	2003	14 (138 MM)	KAIST(11/128MM), UCB(3/10MM)
Joint Lecture	2004	1 (58 Attendees)	KAIST(11)+UCB(47)
Joint Publications	2006	8	

KAIST — Korea Advanced Institute of Science and Technology

University of California at Berkeley (UCB)
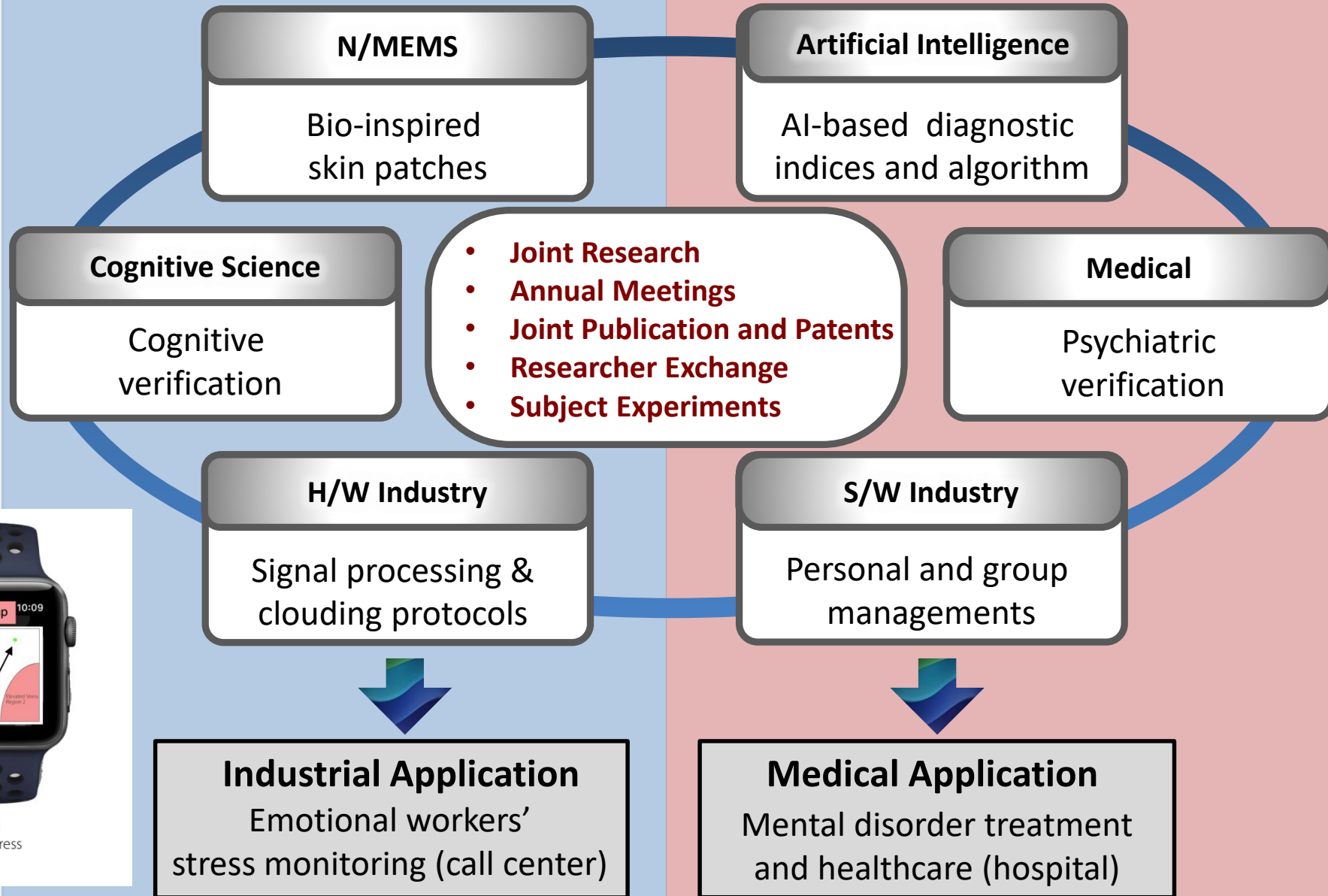
University of California at San Diego (UCSD)

University of Michigan

CHILDREN'S HOSPITAL & RESEARCH CENTER OAKLAND

Proposed Collaboration on
AI-based Human Stress Monitoring and Management

N/MEMS
Bio-inspired skin patches

Artificial Intelligence
AI-based diagnostic indices and algorithm

Cognitive Science
Cognitive verification

- **Joint Research**
- **Annual Meetings**
- **Joint Publication and Patents**
- **Researcher Exchange**
- **Subject Experiments**

Medical
Psychiatric verification

H/W Industry
Signal processing & clouding protocols

S/W Industry
Personal and group managements

Industrial Application
Emotional workers' stress monitoring (call center)

Medical Application
Mental disorder treatment and healthcare (hospital)

Stress map 10:09

nt stress position
e to predicted stress

Thank you !