MODEL REFERENCE FUZZY CONTROL SYSTEM OF BRAIN TEMPERATURE FOR HYPOTHERMIA TREATMENT

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Hypothermia Protection of Brain Tissue

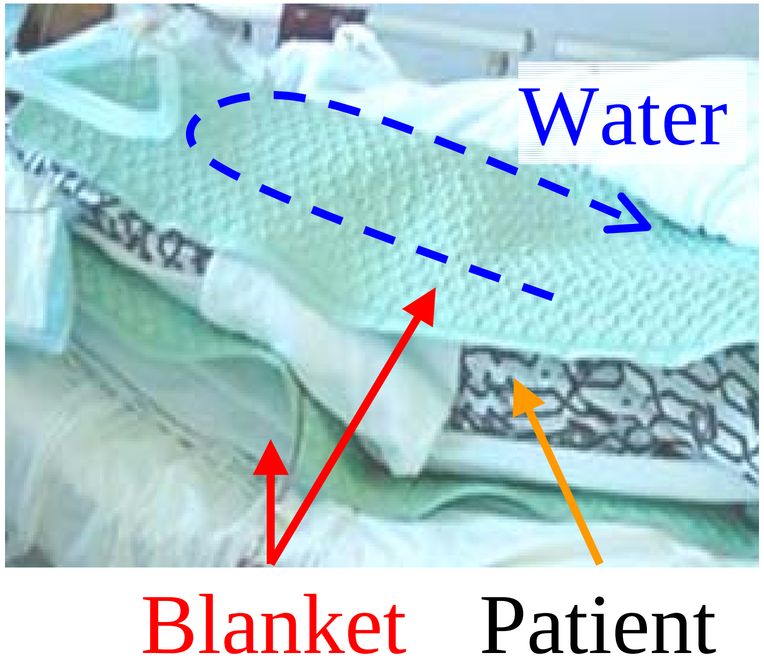
Treatment in the acute stage of irreversible brain damage
Cooling brain for the protection of its secondary damage

Surface cooling method

Wash out metabolic heat of brain by cooled blood flow which is supplied from the whole body circulation

Dilemma by surface cooling

Constitutional effects caused by biochemical environment
Seriously physiological invasion



Accurate control of brain and body temperature

Background of the Study

Accurate control of brain temperature by determination of water temperature based on its measurement in every 20min

but

Requiring high level knowledge and technique

Intracranial pressure，Anesthesia, Respiration, Immunology, etc. → Heavy burden on medical staff

→ In a long term (1 week to 1 month)

Automatic management → **Relief from physical & mental stress**
Spread & prevalence of the method

Automatic control of brain temperature

Introduction to the present method

Accurate control of brain temperature by Optimal-Adaptive Control (Pure mathematical method)

does not always meet medical staff's view points

on the basis of their clinical experience

Control system based on clinical experience

➡ Human friendly control of brain temperature

Its realization? Fuzzy Control

Basic Policy and Principle

- Human friendly automatic control of brain temperature
- Unknown factors or ambiguous knowledge about controlled object beforehand
- Based on clinical experience using commonly understood thermal characteristics of patients

Management of treatment by medical staff

On the basis of clinical experience， water temperature is determined to follow up desired brain temperature.

Accordingly, appropriate of temperature water is given, when clinical experience does not match with actual response.

Synthesis of control system

Introduction of characteristic model

Thermal characteristics of patients, known as approximately **first order lag system** according to clinical experience

Characteristic model

$$\tilde{T}^{ch}_{brain}(k) = -a\tilde{T}^{ch}_{brain}(k-1) + b\tilde{T}^{ch}_{water}(k-1)$$

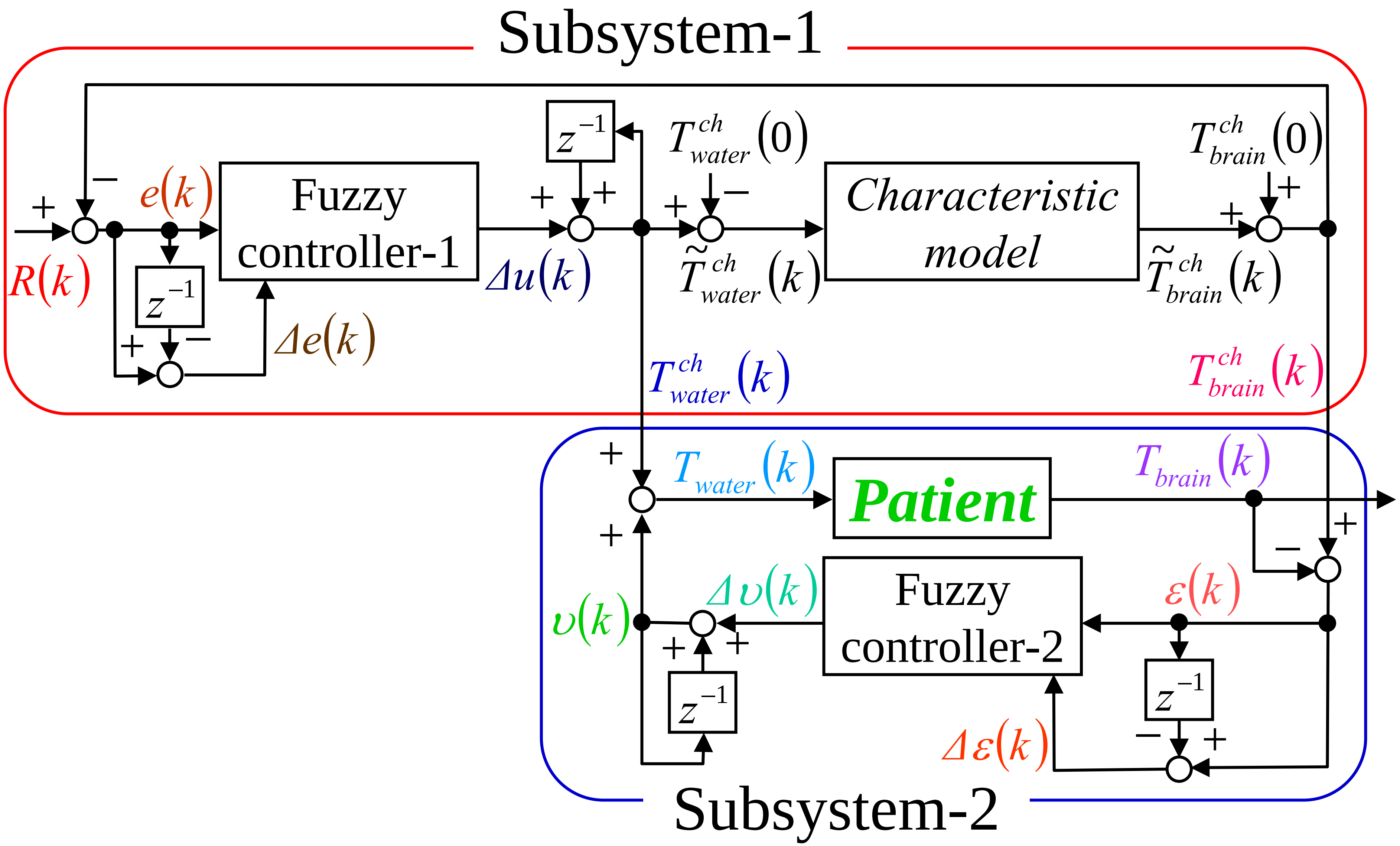
$$a = -\exp(-\nu/\tau) \quad b = (1-K)\exp(-\nu/\tau)$$

$$T^{ch}_{brain}(0) = T_{brain}(0) = R(0)$$

$$T^{ch}_{water}(0) = T_{water}(0)$$

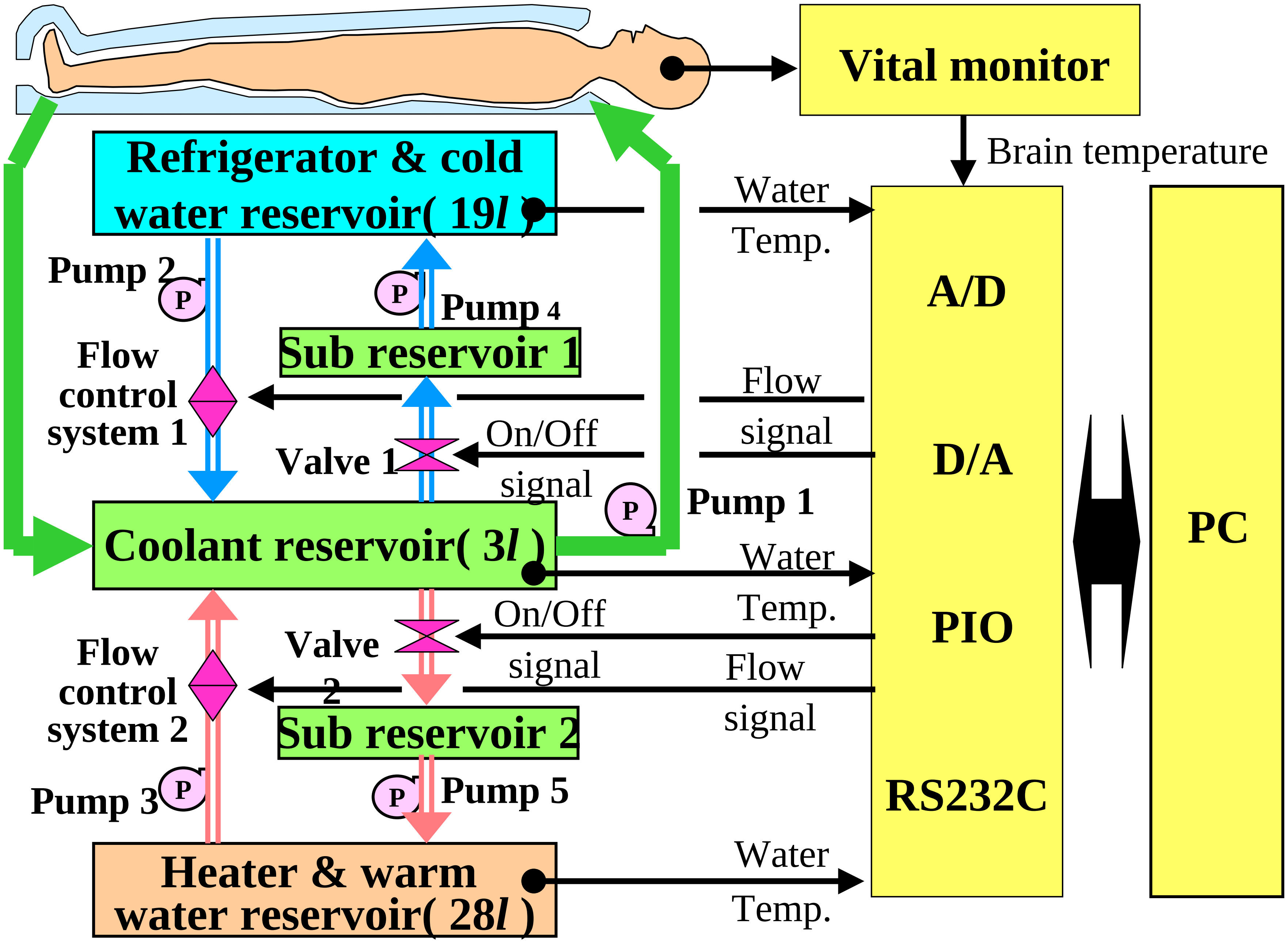
K : Gain
τ : Time constant
ν : Sampling time

Block diagram



Symbols in the block diagram

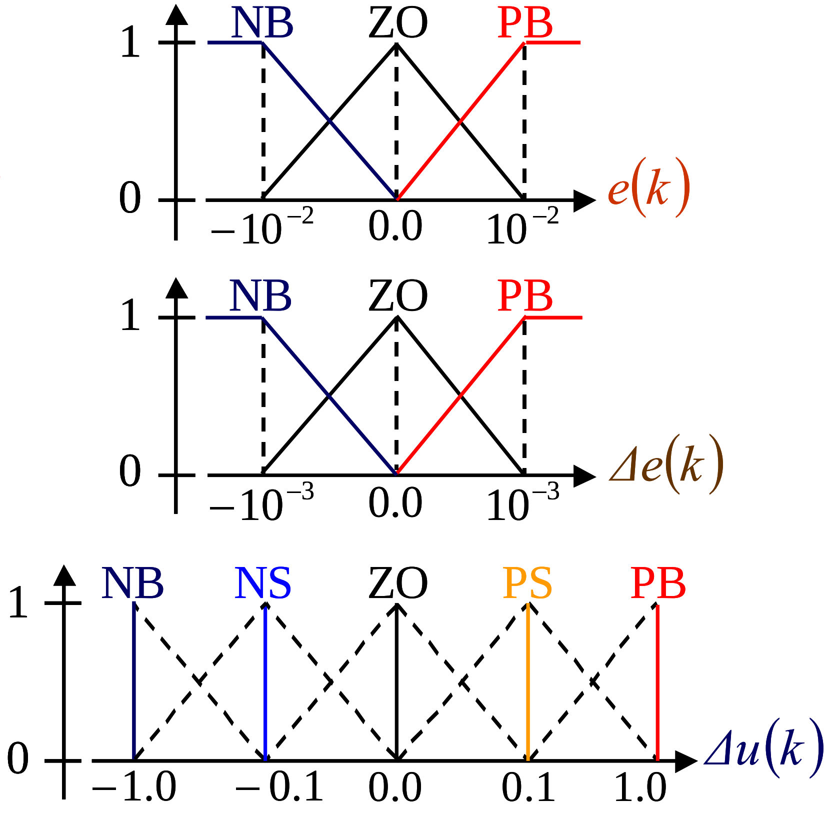
$R(k)$	Desired brain temperature
$T_{water}^{ch}(k)$	Water temperature of characteristic model
$T_{brain}^{ch}(k)$	Brain temperature of characteristic model
$T_{water}(k)$	Water temperature of patient
$T_{brain}(k)$	Brain temperature of patient
$\upsilon(k)$	Compensatory value of $T_{water}^{ch}(k)$
$e(k)$	Controlled deviation between $R(k)$ and $T_{brain}^{ch}(k)$
$\varDelta e(k)$	First difference of controlled deviation of $e(k)$
$\varDelta u(k)$	First difference of operated value deviation of $T_{water}^{ch}(k)$
$\varepsilon(k)$	Controlled deviation between $T_{brain}(k)$ and $T_{brain}^{ch}(k)$
$\varDelta\varepsilon(k)$	First difference of controlled deviation of $\varepsilon(k)$
$\varDelta\upsilon(k)$	First difference of operated value of $\upsilon(k)$



Mechanical Structure of brain temperature control system by water cooling

Membership functions and Fuzzy rule

For fuzzy controller-1



The antecedent

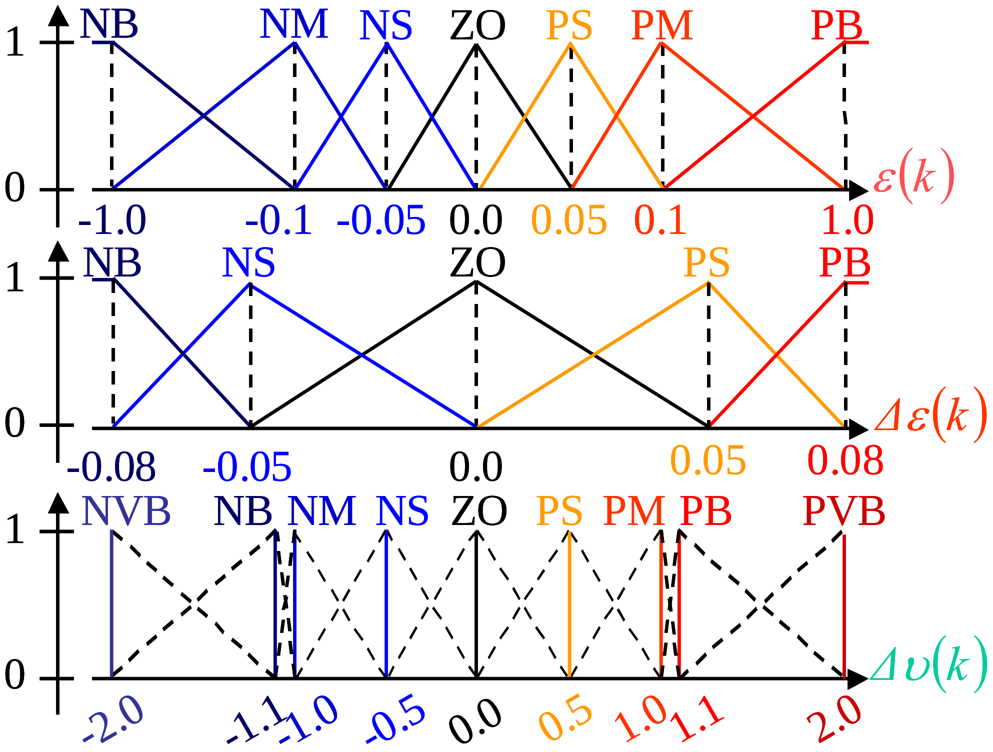
$\Delta u(k)$		$e(k)$		
		PB	ZO	NB
$\Delta e(k)$	PB	PB	PS	ZO
	ZO	PS	ZO	NS
	NB	ZO	NS	NB

The antecedent

The consequent

Membership functions and Fuzzy rule

For fuzzy controller-2



The antecedent

The antecedent

$\Delta\upsilon(k)$		$\varepsilon(k)$						
		PB	PM	PS	ZO	NS	NM	NB
$\Delta\varepsilon(k)$	PB	PVB	PVB	PS	ZO	PVB	PVB	NM
	PS	PVB	PVB	PS	ZO	PM	PB	NB
	ZO	PVB	ZO	ZO	ZO	ZO	ZO	NVB
	NS	PB	NB	NM	ZO	NS	NVB	NVB
	NB	PM	NVB	NVB	ZO	NS	NVB	NVB

The consequent


Refrigerator & cold water reservoir
Automatic control apparatus
Cooling-blanket
Heater & warm water reservoir

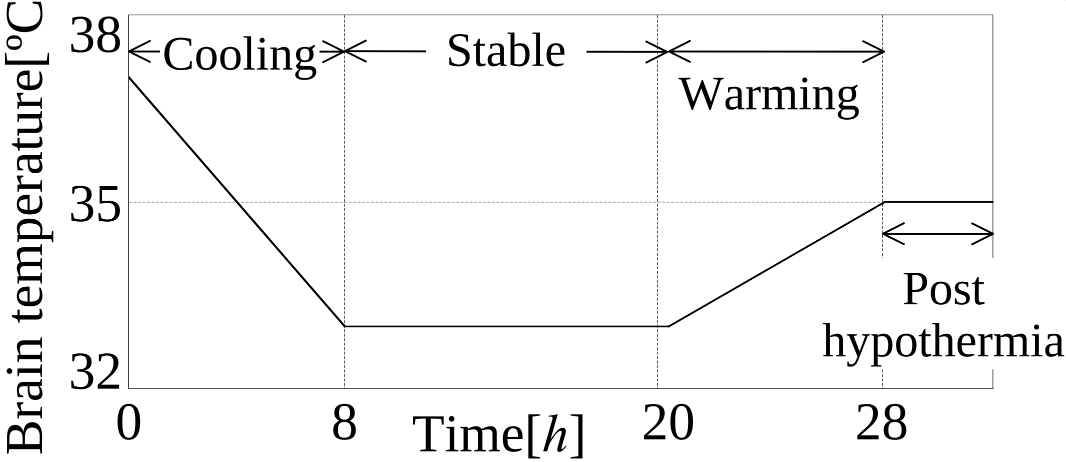
Experimental Method

Experimental subject

Mannequin in water tubs
imitating circulation

Heaters in head, chest,
abdomen & extremities
imitating metabolism

Desired brain temperature

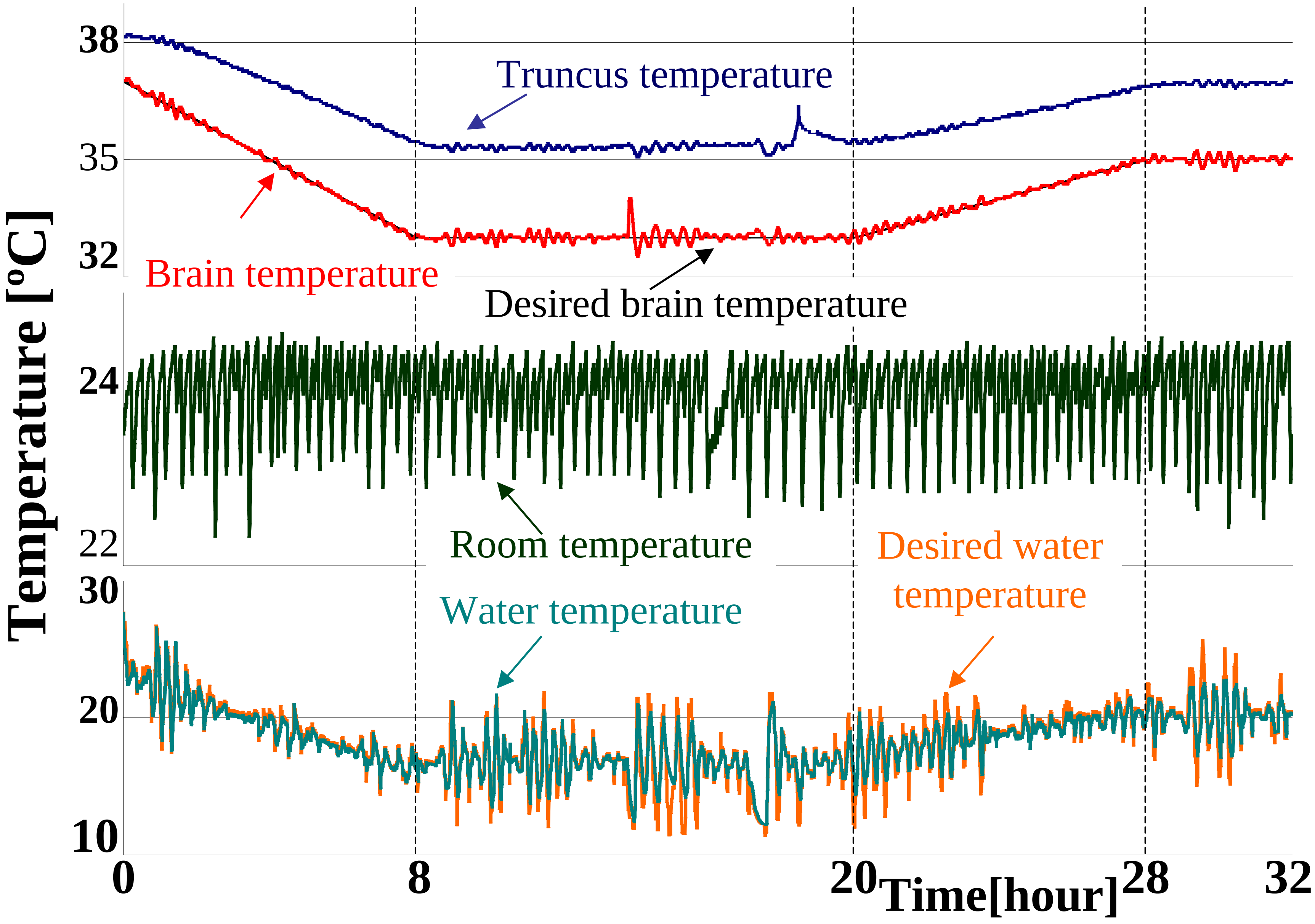


Experimental Condition

Thermal characteristic & environmental change

- Stop of pump for circulation in 2 min
circulatory blood amount change
- Heater in head switched on in 30 sec
brain metabolic rare rises
- Windows opened in 20min
room temperature change
- Covering blanket partly taken off in 10min
change of heat conductive condition
- Heater exclusive of head witched on in 1.5min
constitutional metabolic rate change

Experimental result



Discussion

- Brain temperature being kept within ±0.3[°C] without any intentional environmental change
- Brain temperature control being hardly affected by various change of environment

Fuzzy Control System

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To become useful powerful method

Summary

- Usefulness of fuzzy automatic control for brain hypothermia
- Effect of brain temperature by metabolic, circulatory change in its various parts of body using mannequin
- High expectation of its clinical use

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Future study

- More accurate control of brain temperature
- Animal experiment and clinical application
- Some special treatment under the precise control of body temperature