Characteristics of Core-Temperature Transmission Changes According to The Morphological Structural Flow Within the Ear

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Abstract:Inner-ear temperature can be measured using a variety of methods. While it is possible to measure microtemperature using standard methods, directly measuring the temperature of the vacuum itself—which is necessary for evaluating microtemperature in the inner ear—is extremely difficult; therefore, clinicians rely on indirect vestibular function responses. The method used is the caloric test, which utilizes changes in vacuum pressure. This method involves introducing warm or cold water into the external auditory canal, or blowing warm or cold air to induce convection in the endolymph, thereby observing changes in firing patterns between the vestibular nerves in the semicircular canals and detecting nystagmus in the vacuum to assess any changes. However, this measurement method has the drawback of causing slight physical changes in the vestibular nerves.

We aim to measure very small temperature changes using this core-transmission measurement method. The basic system for this non-invasive method uses an IR sensor for detection and measurement; since the process of calculating the resulting measurement values proceeds relatively smoothly, the core-transmission method is used to display the temperature on the screen. The core-transmission measurement system (CTMS) consists of a component that receives the heat measured by the heat-sensing IR sensor via the core method. The data obtained from analog measurements is converted into digital signals via an ADC and then processed by a microprocessor to produce usable data. In the conventional method, the temperature measurement range was from 30°C for a cold stimulus to 44°C for a warm stimulus. However, with the CTMS method, a significant vestibular response was observed even within a measurement range of approximately ±7°C, and it was confirmed that the vestibular system could detect even minute changes of 0.1–0.3°C.

Therefore, the CTMS method can be expected to be modeled as a process that measures changes in slow-phase velocity to estimate changes in vestibular hypofunction. The method using an infrared (IR) sensor can be expected to be a system that minimizes temperature errors.

Keywords:Core-transmission measurement system, Core-transmission measurement, IR sensor, Digital signals.

Introduction

Core body temperature (CBT) is an important indicator of human health and endurance performance. Characteristics of CBT and the ideal measurement site are utilized in clinical and physiological fields to estimate core body temperature using the tympanic membrane and infrared thermometers (Pompei et al., 2004). While continuously wearing a sensor on the tympanic membrane is impractical, the sensor must be placed at the entrance to the ear canal. However, the tympanic membrane is subject to temperature gradients extending to the external ear, which are influenced by ambient air temperature and wind (Pompei et al., 2004 Pompei et al., 1996). These temperature gradients make temperature estimates sensitive to sensor placement. The double sensor configuration model can minimize the impact of the surrounding environment and improve the overall accuracy of core body temperature estimates across various environmental conditions. Measuring tympanic temperature (Ttm) with infrared thermometers is gaining attention as a potential alternative to the invasive temperature measurement procedures discussed earlier. However, despite being a safe, noninvasive, and convenient method for measuring Ttm, issues regarding accuracy and stability remain unresolved to some extent compared to other measurement methods (Lattavoet al., 1995; Fulbrook, 1997; Robinson et al., 1998; Roth et al., 1996).

Ben Zinger (Benzinger et al., 1959; Benzinger et al., 1969; Benzinger, 1969) was the first to demonstrate the feasibility of measuring Ttm as an indicator of CBT using a thermocouple probe on the surface of the eardrum, while the eardrum was isolated from the external auditory canal. Benzinger noted that the eardrum is very close to the hypothalamus and the internal carotid artery and is an accurate indicator of CBT; he presented Ttm measurements obtained using this probe and measurement approach, demonstrating that these values are stable, reproducible, and responsive to various thermal stresses.

Studies by McCaffrey et al. (McCaffrey et al., 1975) and Nielsen (Nielsen, 1988) revealed that head cooling reduces Ttm, particularly when cooling is concentrated on the face. McCaffrey et al. demonstrated that by heating and cooling specific areas of the head, human Ttm is affected in a manner that is not proportional to changes in scalp temperature; consequently, CBT is influenced not only by Ttm but also by other variables.

Brinnel and Cabanac(BrinnelandCabanac, 1989) as reported by Sato et al. (Sato et al., 1996), proposed using a probe to access specific points on the surface of the eardrum. Brinnel and Cabanac suggested that the measurement point located in the anterior quarter of the lower eardrum would exhibit the highest temperature and be most sensitive to cooling of the head or face. Sato et al. located the probe to identify the hottest point on the eardrum. The probe attached to the eardrum interpreted the results in a flat field, assuming that convective heat loss would be minimized at all measurement points due to contact. Since the eardrum is not flattened but conical in shape, it must be physically secured. The temperature measured on the eardrum should be taken at a proximity to the eardrum itself to ensure that the hottest area is selected fairly. When measuring Ttm by stimulating the eardrum, the selection of the hottest point must be addressed in the future (BrinnelandCabanac, 1989; Sato et al., 1996). Sato et al. established no specific boundary for this point, while Brinnel and Cabanac proposed the anterior quarter of the lower part of the eardrum. Selecting the point with the highest temperature is likely to be the most stable against environmental influences and is performed at an ambient temperature lower than that for CBT. The heat flow reverses direction, causing the body to seek cooler areas to regulate body temperature and maintain CBT in response to external heat stress.

The inner ear is anatomically located deep within the petrous bone, making it a highly stable structure protected from external environmental changes. The temperature of the inner ear is characterized by relative constancy. This physiological property of inner ear temperature results in high thermal stability, largely unaffected by external temperatures due to the protection provided by the petrous bone, lymph fluid, and bone structure. The temperature of the inner ear is almost entirely dependent on blood flow. Changes in temperature are blood-flow dependent, occurring primarily due to variations in blood flow through the inner ear artery, the vestibular artery, and the cochlear artery. The inner ear possesses a function sensitive to minute temperature changes. Even a 0.1°C change can alter the response of the vestibular system (VOR gain). Temperature changes affect the viscosity and flow velocity of the endolymph, as well as the firing rate of the vestibular nerve, leading to alterations in vestibular function. That is, while the vestibular organs are sensitive to temperature, their anatomical structure results in very minimal actual temperature changes (Beskok and Karniadakis, 1999).

The system configuration employing a core-based method for detecting and measuring temperature incorporates core-transmission measurement methods as its primary component. Data measured at depth is converted into digital signals via an Analog-Digital Converter. The resulting digital data is processed through a microprocessor to form usable converted data, which undergoes further transformation through computational processes within the system. The converted data is transformed into communication values, acquiring signal characteristics that enable its use under conditions necessary for conversion deep within the human body. Therefore, non-contact systems using core-transmission measurement methods fundamentally utilize measured data, which changes with body conditions, to measure temperature variations necessitated by positional changes. They aim to analyze deep body temperature through non-contact signals from deep body thermometers via attached sensor devices (Chandika et al., 2015; Fujino et al., 2011).

Theory

Core-Transmission Measurement Procedure

Core-transmission measurement procedure (CTMP) is a method for evaluating very small temperature changes, as shown in Figure 1. Since it is extremely difficult to directly measure the temperature of the inner ear itself, clinical practice utilizes indirect vestibular function responses. The most representative test method utilizing changes in inner ear temperature is the caloric test. The principle of operation involves introducing warm or cold water into the external auditory canal, or injecting warm or cold air, to induce convection in the endolymph. This induces changes in firing activity in the vestibular nerve within the semicircular canals and generates nystagmus originating in the inner ear, allowing these changes to be detected and examined. The temperature range applied for measurement in the inner ear is 44°C for warm stimulation and 30°C for cold stimulation. The required measurement range is set based on the fact that vestibular responses are significantly elicited even with changes of approximately ±7°C. The sensory state of the vestibular organs can detect even minute changes of 0.1–0.3°C (Akyildiz et al., 2002).

The measurement parameters for the caloric test in CTMP involve measuring changes in the slow-phase velocity of nystagmus, confirming symmetry through bilateral inner ear responses, and estimating changes indicative of vestibular hypofunction. To closely measure blood flow around the inner ear, the system uses an infrared (IR) sensor or thermopile sensor to accurately reflect inner ear temperature, minimizing measurement error. Temperature variations occur at different angles within the inner ear due to its temperature-dependent characteristics (Lichung et al., 2002).

The IR method yields different temperatures measured based on blood flow in vessels beneath the inner ear skin, with variations in response speed and accuracy. To enhance accuracy, the system is configured by assessing the degree of influence on skin blood flow (Akyildiz et al., 2002; (Lichung et al., 2002).

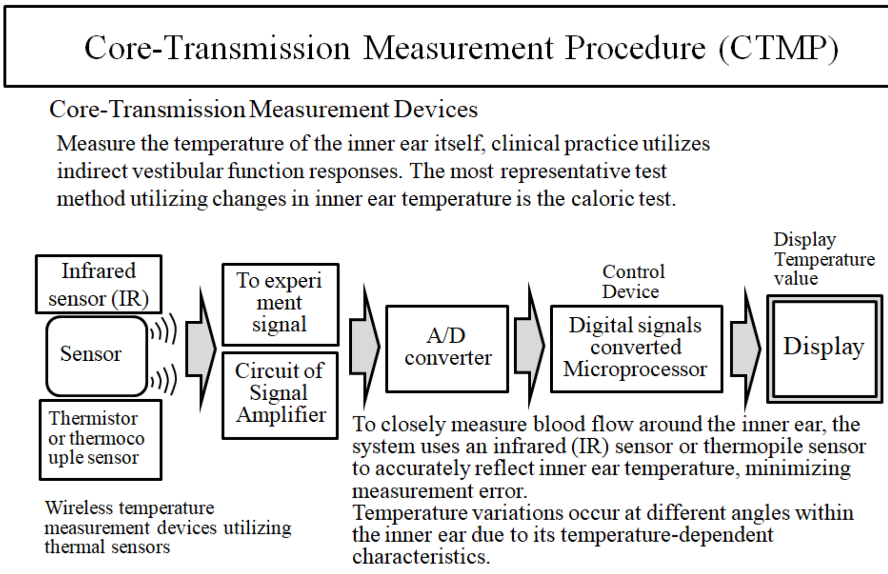


Figure. 1 Mutational Status of Core-transmission measurement Procedure (CTMP) from Infrared Sensor (IR) Functions Based on Foreign Substance and Angle Location on the Body.

Diffuse Vacuum Temperature Methods

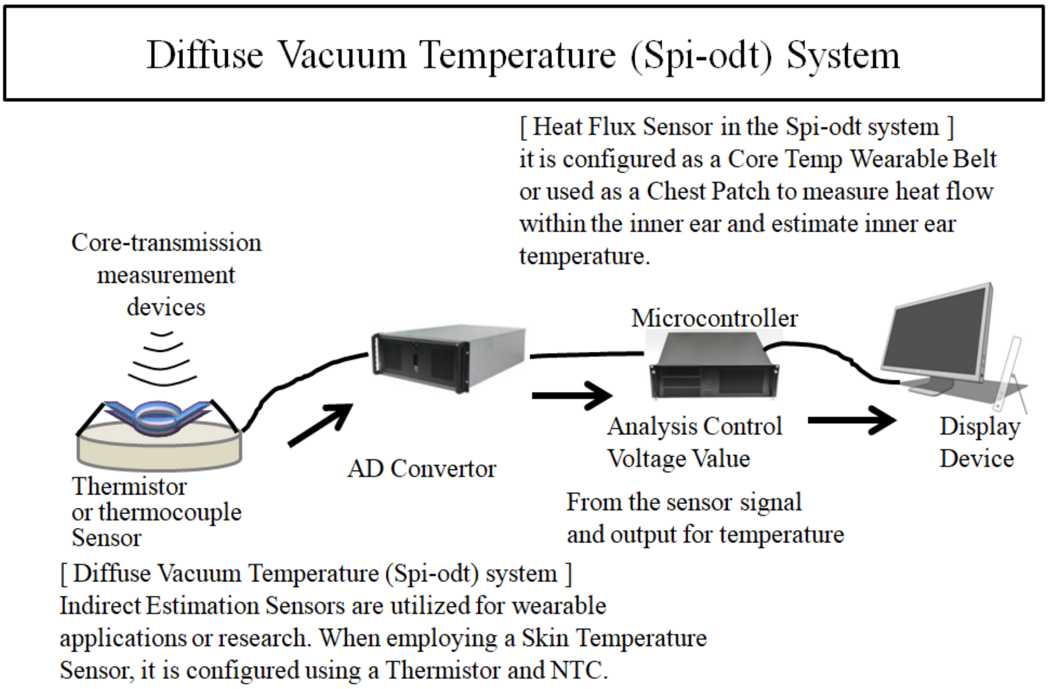
The characteristics of the Diffuse Vacuum Temperature (Spi-odt) system are defined in two forms through spatial comparison (Value Comparison). First, during the measurement of temperature changes between Rectal and Skin, the change in steady state (ΔT) occurs within the range of 3–5°C. When fever or shock occurs, ΔT decreases, and when peripheral blood vessels constrict, ΔT increases. When measuring temperature changes between Tympanic and Oral, a normal state shows a difference of approximately 0.3–0.5°C. If excessive temperature inconsistencies occur within a certain range, measurement errors and hypovolemia should be suspected.

The Diffuse Vacuum Temperature (Spi-odt) system is evaluated based on physiological conditions, specifically exercise, anesthesia, and illness. During exercise, a gradual rise to 39°C is considered normal, while a rapid increase approaching 40°C triggers a risk alert. During anesthesia, the evaluation criterion requires management for hypothermia if the temperature drops below 36.0°C. Suspicion of sepsis is indicated when the temperature remains above 38.3°C or when signs of danger occur at hypothermic temperatures below 36.0°C.

Among the characteristics related to the Diffuse Vacuum Temperature (Spi-odt) system, Indirect Estimation Sensors are utilized for wearable applications or research. When employing a Skin Temperature Sensor, it is configured using a Thermistor and NTC. In the Spi-odt system, using a Core–Skin Gradient model instead of directly reflecting core temperature yields a very rapid response. When using the Heat Flux Sensor in the Spi-odt system, it is configured as a Core Temp Wearable Belt or used as a Chest Patch to measure heat flow within the inner ear and estimate inner ear temperature. When using the Core Temp Wearable Belt configuration, the Spi-odt system ensures a uniform rate of temperature change for the inner ear. However, the dispersed Core Temp may exhibit non-uniform temperature changes depending on its location.

Diffuse Vacuum Temperature Form

The evaluation criteria for sensors used in the Diffuse Vacuum Temperature Form (Dif-VTF) also apply when used as wearable or skin sensors. The signal-to-noise ratio (SNR) is >20 dB under normal conditions and <10 dB under abnormal conditions. When reconstructing the Core-transmission signal in the Dif-VTF, the Cut-across Vacuum Temperature recognition rate and signal are provided via the Diffuse Core-transmission measurement Level (Dif-CTML), and the mechanism is used to calculate the measured Cut-across Vacuum Temperature value. The RMSE, representing the model error of the Core–Skin Gradient, is < 0.3°C for normal temperatures and > 0.5°C for abnormal temperatures. While generally stable, sudden spikes occur during irregular fluctuations in continuous data variability. The Core-transmission measurement values shown in Figure 2 are clearly distinguished by the Cut-across Vacuum Temperature signal. The generated signal based on cut-across vacuum temperature serves as the foundation for core temperature estimation. It focuses on the thermal gradient derived from skin temperature and HRV generated by the human body, enabling wearable measurement of core temperature through modeling using machine learning techniques, and facilitates continuous monitoring (Kim et al., 2017; Kim et al., 2017).



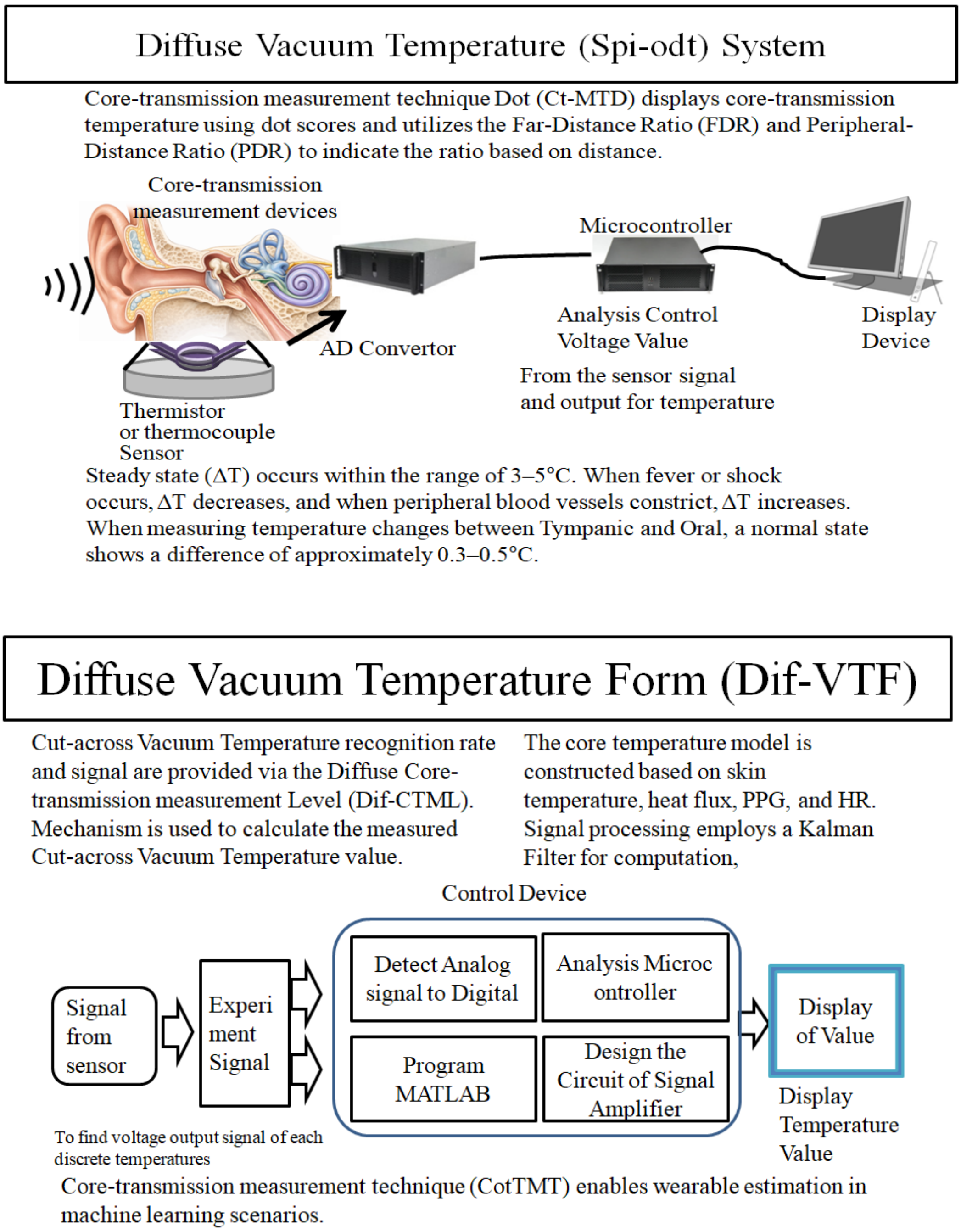


Figure2. System block of Diffuse Vacuum Temperature Form (Spi-oDTF) is technology on the diffuse core-transmission measurement with by Cut-across vacuum Technique

Core-transmission Measurement Technique Dot

In the Core-transmission measurement technique dot (Ct-MTD), the temperature data acquisition method involves receiving analog signals from thermistors or thermocouples at the sensor. These signals pass through a Wheatstone bridge to measure a constant voltage, and the resulting voltage difference is converted into a digital value by an ADC converter to obtain the changed signal. The digitized signal undergoes data processing through the MCU. Relevant parameters require calibration for temperature compensation. The Steinhart–Hart equation is applied to fit the NTC curve, and Kalman Filtering is used for low-pass filtering."

Core-transmission measurement technique Dot (Ct-MTD) displays core-transmission temperature using dot scores and utilizes the Far-Distance Ratio (FDR) and Peripheral-Distance Ratio (PDR) to indicate the ratio based on distance. The standard deviation appearing in the center layer at the white-refinement dot is expressed as a ratio of the lateral layer and surrounding position path, enabling its use per unit affecting the human body. In the Core-transmission measurement technique Dot (Ct-MTD), measurements using an IR sensor employ a measurement device configured with a Thermopile or IR Sensor. An MCU with an internal DSP transmits digital signals via I²C or SPI. Ambient temperature compensation is an essential requirement. In the Core-transmission measurement technique Dot (Ct-MTD), the use of a ZHF sensor requires maintaining zero loss through feedback heater control that minimizes heat loss from the skin. Steady-state skin must form the core value, and control is achieved via digital output through the module (Kimet al., 2014; (Kim et al., 2016).

In the Core-transmission measurement technique Dot (Ct-MTD), the Zero-Heat-Flux connection is configured with a reciprocal ratio between the distance and the gap, and calculated by measuring the correlation between surfaces. The heat generated from the skin was calculated using a method that calibrates the external heat loss between the insulating pad attached to the skin and the measurement sensor to ‘zero’. This method then calculates the temperature change as heat moves inward from the external skin temperature. The accuracy of the changed temperature was set to ±0.1~0.2°C, enabling signal acquisition and sensitivity measurement.

ΔP is represented as a dot score in Ct-MTD, reflecting the energy quantity proportional to the ratio of core-transmission temperature to distance Equation (1).

“I and Q” are represented as the modulated Ct-MTD carrier, while the Cc-FC carrier is the measurement value located at a distant point via Ct-MTD. The Cc-FV carrier represents the position between adjacent distances via Ct-MTD. In Equation (1), ΨPCt-MTD transmits the received signal, via modulated amplitude and phase, to the reconstructed signals ICc-FC and QCc-FV at Ct-MTD (Huiting et al., 2013; Bekkali et al., 2015). In Equation (2), ΨPCt-MTD-FC, ΨPCt-MTD-FV, (absolute value: Ψγ) are calculated..

$$\Delta P_{Ct-MTD} = \frac{I^2_{Ct-MTD-FC}+Q^2_{Ct-MTD-FV}}{Z_0}, \quad \Psi = \arctan\frac{Q_{Ct-MTD-FV}}{I_{Ct-MTD-FC}} (1)$$

$$|\Delta_\gamma| = \sqrt{I^2_{Ct-MTD-FC} + Q^2_{Ct-MTD-FV}} = \sqrt{\Delta P_{Ct-MTD} + Z_0} (2)$$

The initial value of the receiver input impedance (Z_0) was formed by sequentially displaying the white-refinement dot in ΔPγ to establish an absolute value, while Ψγ was corrected for variations occurring during reception. In Equation (3), the sequential isotropic coefficients were expressed as Ct-MTD-FC and Ct-MTD-FV.

$$\angle(\Delta_\gamma) = \arctan\frac{Q_{Ct-MTD-FV}}{I_{Ct-MTD-FC}} = \varphi \qquad (3)$$

Therefore, in ΔPγ, the change range between the pin and the system in the diffuse-layer is appropriate for setting and configuring the signal's setpoint and was expressed as monitoring (DiGiampaolo et al., 2014).

Core-Transmission Measurement Form

Core-transmission measurement-form (Ct-MF) utilizes surrogate core indicators to measure quasi-core temperature, which can be characterized as follows: Tympanic temperature at the ear canal and eardrum reflects rapid responses due to proximity to cerebral blood flow. Temporal artery temperature offers good accessibility and relatively accurate readings. Oral temperature demonstrates relative stability, maintaining consistency despite influences from eating and breathing.

The core-transmission measurement form (Ct-MF) is expressed as Ct-MF-FV and Ct-MF-FC by the diffuse layer. Ct-MF values were obtained from Ψ-Ct-MTD values, FV-FC, and Ψ-Ct-MTD. The Ψ-Ct-MTD used is based on the Ct-MF in Equation (4). Core-transmission measurement-form (Ct-MF) is expressed as Ct-MF-FV and Ct-MF-FC by the diffuse layer. The Ct-MF value is derived from the Ψ-Ct-MTD value at the far end of the diffuse layer, while the FV-FC value is obtained from the Ψ-Ct-MTD value at the near end of the diffuse layer. Equation 4 used was formulated based on Ψ-Ct-MTD and Ct-MF.

Ψ-Ct-MTD(r)[n.u.] = $\Psi\text{-}_{Ct-MF-FC}\gamma / r^{\Psi-Ct-MF-FV} \equiv \Psi_{-Ct-MTD(r)}$[dB]

= 20log10($\Psi\text{-}_{Ct-MF-FV}$) − $\Psi\text{-}_{Ct-MF-FC}$ 20log10(r) (4)

'r': Range for depth.

Ψ-Ct-MF-FV: Measurement coefficient for Ct-MF-FV.

Ψ-Ct-MF-FC: Measurement coefficient for Ct-MF-FC.

The diffuse layer of 'r' is set to a reference value using root mean square (RMS) and exhibits nonlinear values. The expressed Ψ-Ct-MTD(r) is an exponential log form for Ψ-Ct-MF-FV and Ψ-Ct-MF-FC (López et al., 2017; Chawla et al., 2013).

Results and Discussion

Diffuse Vacuum Refinement-FormSequence

Core-transmission measurement technique (CotTMT) enables wearable estimation in machine learning scenarios. The core temperature model is constructed based on skin temperature, heat flux, PPG, and HR. Signal processing employs a Kalman Filter for computation, while a neural network-based approach visualizes core temperature estimation. The communication process connects via cloud or embedded inference. Core temperature characteristics were confirmed using diffuse vacuum refinement-form. By measuring core temperature, which reflects the temperature of internal organs, stable human activity was measured. Core-transmission measurement technique (CotTMT) is used to measure the most stable core temperature, reflecting the metabolic activity of organs such as the brain, heart, liver, and internal organs.

Diffuse vacuum refinement-form (Dif-VRF) is a white-refinement-dot form that identifies the core temperature as the Cut-across vacuum refinement rate (Cua-VTR). The white-refinement-dot rate (Ws-DR) for obtaining the Dif-VRF-temperature is generated by constraining the Cut-across vacuum rate (SDR) within the diffuse vacuum refinement-form system (Dif-VRFS). The altered state of the Cut-across temperature rate (STR) is expressed by the core-transmission vacuum refinement-form activity (CotVFA) experiment, and the Dif-VRF values for the temperature form were derived as Dif-VRF-ΨMAX-MED, Dif-VRF-ΨMED-MIN, and Dif-VRF-ΨMED. The collected database is in the diffuse signal temperature form where Dif-VRF activity is possible, and the data in Table 1 is in the diffuse signal temperature form. (Matlab 6.1 experimental calculation).

Table 1. Average of diffuse reorganize temperature-forms: the CUA-VTR (Dif-VRF-FA$\Psi_{MAX-MED}$), CUA-VTR (Dif-VRF-CO$\Psi_{MAX-MED}$), CUA-VTR (Dif-VRF-FL$\Psi_{MAX-MED}$) and CUA-VTR (Dif-VRF-VI$\Psi_{MAX-MED}$) condition. Average ofDif-VRF-Ψ_{MED} and Dif-VRF-$\Psi_{MED-MIN}$.

Average Ψ	FA $\Psi_{Avg-CUA-VTR}$	CO $\Psi_{Avg-CUA-VTR}$	FL $\Psi_{Avg-CUA-VTR}$	VI $\Psi_{Avg-CUA-VTR}$
Dif-VRF-$\Psi_{MAX-MIN}$	16.32±2022	5.56±0.79	2.95±1.5	0.39±0.18
Dif-VRF-$\Psi_{MAX-MED}$	9.76±2.07	3.64±0.09	2.05±1.33	0.29±0.16

Improvements of Diffuse Vacuum Refinement-Form Sequence Selections

In the diffuse vacuum refinement-form, the interpretation of core temperature data indicates that during the process of measuring temperature changes in body temperature, a state where the short-term fluctuation range does not change drastically is considered normal. However, if a change in body temperature occurs where the change within one minute, ΔT, is greater than or equal to 0.2°C, it is judged as abnormal. The cause of this judgment is presumed to be errors, sensor detachment, changes in blood flow, shock, etc.

Dif-VRF of Comparison Database onDif-VRF-FA-ΨMAX, Dif-VRF-FA-ΨMED, and Dif-VRF-FA-ΨMIN Bro-CL-Θ_{MAX} and Bro-CL-Θ_{MIN} and Bro-CL-Θ_{MIN}

Far(FA-Ψ) in the diffuse vacuum refinement-form (Dif-VRF) expresses the cut-across vacuum temperature rate (CUA-VTR) value as Dif-VRF-FA-ΨMAX, Dif-VRF-FA-ΨMED, and Dif-VRF-FA-ΨMIN based on changes in core temperature.

The cut-across core transmission of Dif-VRF-FA-ΨMED showed significant changes in flank-vicinage (FV) using Dif-VRFS. The CUA-VTR's Dif-VRF, using Dif-VRF-FA-ΨMAX and Dif-VRF-FA-ΨMIN, showed small changes in Diffuse identified as Diffuse. The Diff-VRF-FA-ΨMAX for Diffuse formed a very large value change of 19.30±8.77 units. Dif-VRF-FA-ΨMIN of Dif-VRF showed a value of 4.62±1.45, confirming significant changes in the distant CUA-VTR manifested as Diffuse. Figure 3 reconstituted the distant CUA-VTR in Diffuse form, revealing an uneven pattern in the core-temperature Dif-VRF-Far. Dif-VRF-FA-ΨMIN showed a large Diffuse value of 4.62±1.45 in Dif-VRFS. The core transmission in the distant CUA-VTR, influenced by core-temperature changes, exhibited a large Diffuse-type Dif-VTF in the Dif-VRF direction, with Dif-VRF-FA-ΨMED showing a value of 8.98±1.32. Analysis of core temperature data for evaluating the trend of the waveform of the Convenient (CO-Ψ) diffuse vacuum refinement-form (Dif-VRF) revealed an ascending and descending pattern in body temperature. In the normal pattern, a gradual rise was observed during exercise and evening hours, while a gradual decline occurred during rest and sleep periods. In abnormal patterns, an acute rise of 1°C within 1 hour occurs when infection is present or due to central fever phenomena. Persistent high fever (>38.5°C) may also progress. When rising without infection, such as in heatstroke or thyroid storm, non-febrile hyperthermia occurs.

Convenient (CO-Ψ) parameter of the diffuse vacuum refinement form (Dif-VRF) is expressed as the CUA-VTR values of Dif-VRF-CO-ΨMAX, Dif-VRF-CO-ΨMED, and Dif-VRF-CO-ΨMIN. Dif-VRF by CUA-VTR identified some diffuse state values in Dif-VRFS as Dif-VRF-CO-ΨMAX and Dif-VRF-CO-ΨMED due to core-temperature variations. For cut-across core transmission, the Diff-VRF-CO-ΨMAX value was identified as the Diffuse FC of Dif-VRF-CO-ΨMIN, with a Diffuse state value of 8.05±0.90. In CUA-VTR, the depth-dependent Diffuse temperature-form shows a value of 5.31±0.51 in the Diffuse region of Dif-VRF-CO-ΨMED, indicating a large Diffuse region. The CUA-VTR showed a fluctuating state with greater temperature variation than Dif-VRF-CO-ΨMED due to core-temperature changes at depth.

Flank (FL-Ψ) of diffuse vacuum refinement-form (Dif-VRF) core temperature data can be interpreted by spatial comparison using Value Comparison, such as comparing rectal and skin temperatures. When vacuum temperature is normal, the change range is ΔT = 3–5°C; in cases of fever or shock, the ΔT range is reduced. During peripheral vasoconstriction, an increase in ΔT occurs. Comparing Tympanic and Oral temperatures shows a difference of approximately 0.3–0.5°C in normal conditions. Excessive discrepancy may indicate measurement error or suggest hypovolemia. The Flank (FL-Ψ) of the diffuse vacuum refinement form (Dif-VRF) exhibited a cut-across vacuum refinement rate (CUA-VTR) value in the Dif-VRF-FL-ΨMAX, Dif-VRF-FL-ΨMED, and Dif-VRF-FL-ΨMIN cases, reflecting changes in core temperature. In CUA-VTR, the activity of Dif-VRF showed less diffuse refinement in Dif-VRF-FL-ΨMIN and Dif-VRF-FL-ΨMED. At normal vacuum temperatures, Dif-VRF-FL-ΨMAX exhibited low diffuse at 2.46±0.42, and Dif-VRF-FL-ΨMAX represents a temperature pattern where diffuse is reconfigured in the FV direction by Dif-VRFS. Dif-VRF-FL-ΨMIN showed a slightly smaller value of 1.17±0.11, and diffuse was slightly observed in the FC direction from Dif-VRFS. Dif-VRF-FL-ΨMED showed a value of 1.49±0.11, confirming that the Diffuse'sDif-VRF activity exhibited low Dif-VTF. When vacuum temperature is normal, the Flank of CUA-VTR appears diffuse, generating values that change in the same direction as Dif-VRFS in Dif-VRF-FL-ΨMAX due to core-temperature variations.

Vicinage (VI-Ψ) of diffuse vacuum refinement-form (Dif-VRF) core temperature data must be interpreted based on physiological conditions. During exercise, the assessment criteria indicate a normal state when the temperature gradually rises to 39°C, while rapidly approaching 40°C signifies a dangerous state. During anesthesia, a drop below 36.0°C necessitates hypothermia management. A sustained temperature above 38.3°C or below 36.0°C should be considered a risk indicator. In the physiological condition-based assessment, Vicinage (VI-Ψ) of diffuse vacuum refinement-form (Dif-VRF) presented cut-across vacuum temperature rate (CUA-VTR) values as Dif-VRF-VI-ΨMAX, Dif-VRF-VI-ΨMED, and Dif-VRF-VI-ΨMIN. Dif-VRF-VI-ΨMAX, Dif-VRF-VI-ΨMED, and Dif-VRF-VI-ΨMIN confirmed that diffuse occurrence of Dif-VRF activity in CUA-VTR is caused by changes in core temperature. In the physiological condition-based evaluation, Dif-VRF-VI-ΨMAX showed very little diffuse activity, with a value of approximately (0.44±0.10), and it was confirmed that the temperature pattern diffused in the FC direction due to Dif-VRFS. Dif-VRF-VI-ΨMIN exhibited a very low diffuse state with a value of (0.21±0.02), and Dif-VRF-VI-ΨMIN was in the FC direction in Dif-VRFS. Dif-VRF-VI-ΨMED showed a very slight (0.27±0.01) value in Diffuse'sDif-VTF due to core-temperature changes. In the physiological condition-based evaluation, Dif-VRFS adjacent to

CUA-VTR exhibited a phenomenon where it occurred in the same direction as Dif-VRF-VI-ΨMAX. Diffuse vacuum refinement-form (Dif-VRF) core temperature data from sensor-based evaluation indicates that when using wearable skin sensors, the signal-to-noise ratio (SNR) must be > 20 dB under normal conditions and < 10 dB under abnormal conditions to prevent anomalies. Core–Skin Gradient model error (RMSE) is abnormal if < 0.3°C under normal conditions or > 0.5°C. Variability in continuous data indicates stable conditions, though sudden spikes may also occur.

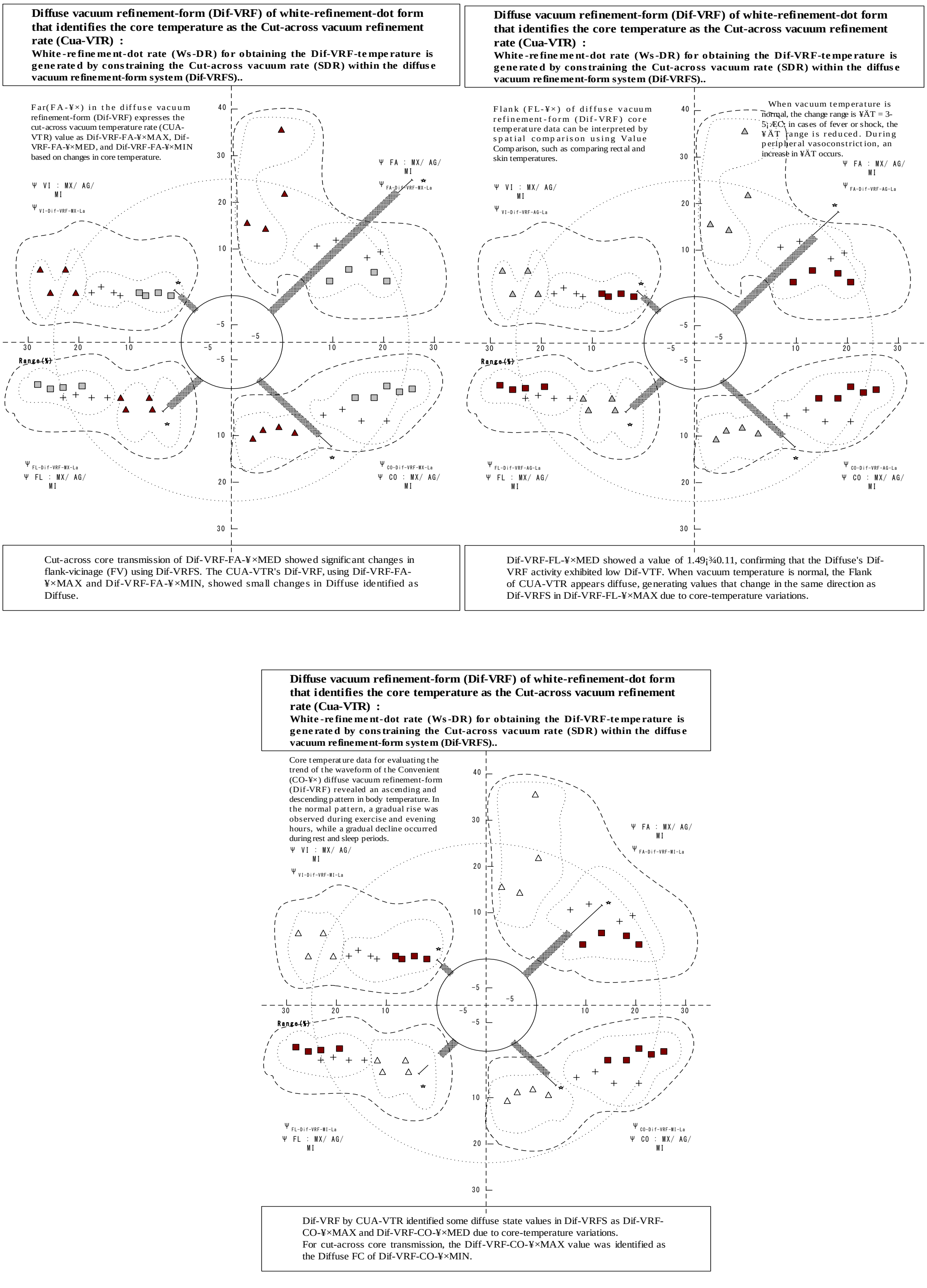


Figure 3. Dif-VRF of the data of Dif-VRF-Ψ_{MED} and Dif-VRF-Ψ_{MIN} and Dif-VRF-Ψ_{AVG} : (a) Min-FA-CO-La-Mi-Sm, Min-FL-VI-La-Mi-Sm (b) Med-FA-CO-La-Mi-Sm // Medx-FL-VI-La-Mi-Sm, (c) (L-3) Med-FA-CO-La-Mi-Sm // Medx-FL-VI-La-Mi-Sm

Conclusion

Core-transmission measurement method is a non-invasive technique that measures temperature with accuracy and precision, demonstrating high reliability. It has been confirmed that, compared to conventional measurement methods, non-invasive contact measurement is more suitable for temperature applications that require high performance and high precision. The measurement process, which involves detection and calculation using an IR sensor, proceeded relatively smoothly, and since the core-transmission method was used to display the temperature on the screen, there were no difficulties in taking the measurements.

Measurements using the conventional method were taken from a cold stimulus of 30°C to a warm stimulus of 44°C, covering a temperature range of 14°C, in accordance with standard measurement procedures. The Core-transmission Measurement System (CTMS) revealed a significant vestibular response, confirming that the vestibular system is sensitive enough to detect even minute temperature changes of 0.1–0.3°C. The results from the Core-transmission Measurement System (CTMS) showed that, depending on distance, the temperature difference was 5.80 ± 1.20 in the far-field region (CTMS-FA-εMED) and 4.06 ± (-0.04) in the intermediate region (CTMS-CO-εMED), a difference of 0.91 ± 0.07 in the oblique region (CTMS-εMED), and a difference of 0.18 ± (-0.03) in the very close region (CTMS-VI-εMED).

Therefore, it is expected that configuring the system using a modeling approach that estimates changes in vestibular hypofunction will yield accurate results. The method using an infrared (IR) sensor is expected to be suitable for systems that minimize temperature errors.

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