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A Technique to Enhance Two-Node Methods as Accurate as Multi-Node Methods: A Case for Human Body Temperature Measurements

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***Abstract*— A human being is categorized as a homoeothermic creature. His stable temperature is controlled using thermoregulation. Hence, his representative temperature is not objectively measured using the one-node method. Meanwhile, multi-node methods are more accurate but inefficient. This study proposed a technique to condense the multi-node (multi-point) method into the minimum number (two-node). This study was a continuation of the author's preliminary study. The human body temperature data for the preliminary study was also reused to make them more manageable for comparison with the preliminary study and to reduce sampling errors. The preliminary study used a 16-node method comprising one node for the core and 15 for skin 1. A (bridge of the nose), 2. B (upper cheek), 3. C (chest), 4. D (upper arm), 5. E (front waist.), 6. F (lower arm), 7. G (hand), 8. L (nape of the neck), 9. M (shoulder blade), 10. N (back waist), 11. H (quadriceps), 12. P (hamstring), 13. J (shinbone), 14. Q (calf), & 15. K (feet). Based on the analysis, the two-node method for this case was the node for the core (ear canal) and upper arm. These two methods were then compared using two-way ANOVA (Analysis of Variance) with Repetition. The result showed no significant difference between the 16-node in the previous study and the condensed multi-node (two-node) method in this study. However, further study should be conducted to condense other multi-node methods, especially two or three-dimensional temperature measurement methods, into the two-node method.**

***Keywords*—Single-node method; two-node method; multi-node method; thermoregulation; heat balance; gender.**

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I. INTRODUCTION

Accurate body temperature measurements of people are essential from the personal level to the global caliber. On an individual level, overvalued temperature measurements may cause a doctor to prescribe overdose antibiotics that can increase superbugs (antibiotic resistance) [1]. In contrast, undervalued temperature measurements lead to additional patient morbidity or mortality [1]. In global caliber, accurate body temperature measurements, for example, are vital to the availability of Coronavirus Disease (COVID) [2], [3], [4]. COVID-19 emerged for the first time in 2019, called COVID-19 [5]. Then, the COVID-19 disease affects, directly and indirectly, many people and activities globally. Many research activities in the fields - such as agriculture [6] and rivers [7], [8] are also shifted from the actual field to laboratories.

Besides security, body temperature measurement is also vital for private comfortability. Psychological comfort and thermal feeling [9], thermal perception [10], thermal injuries [11], and thermal comfort (affective evaluation) [12] are some parameters for private comfortability. The others are thermal preference, personal acceptability, personal tolerance [13], sleeping thermal environments [14] and local heat stress and local heat discomfort [15]. These parameters are subjective. For example, people who wear partially covered clothing can cause an error in predicting the thermal sensation [16].

A temperature measurement might be the one-node (one-point, empirical model), two-node, multi-node (extended two-node), and multi-element methods [17]. The amalgamation among two-node, multi-node, and multi-element methods is called a multi-segmented method [18]. The one-node method is a method that treats the human body as a unit and describes it using a single thermal equilibrium equation without thermoregulatory systems [19]. Two-node models divide the body into the central core and the skin layer. Core body temperature is a primary physiological parameter that shows the human metabolism level and diagnoses various diseases [20]. At the same time, the skin is the human body's largest structure responsible for about 90% of heat loss [21]. Multi-node and multi-element methods divide the body into several elements representing body parts. The difference between them is in the energy balance equation. Energy balance for multi-node is established for all body, while multi-element for each body part.

Another classification shows that the human body measurement method is divided into single-segment and multi-segment methods [22]. The single-segment method is the single-node method, while the multi-segment method consists of the two-node and multi-node methods. The two-node method is a double-node measurement, and the multi-node method is more than a two-point measurement. This study uses this classification, so it does not pay attention to the difference between the multi-node and the multi-element methods but instead to their similarity. Next, both methods are called multi-node methods.

Although old, measuring daily human skin (body surface) temperature is based on single-point measurement. It is widely used because it is more straightforward than the multi-node method. However, the one-node method is less accurate because it cannot reflect the temperature distribution characteristics of different body segments. The human body temperature is heterogeneous for at least two influences.

The internal influence is the source and sinks temperatures in the human body's thermoregulation system to maintain homoeothermic, as the opposite of the poikilothermic phenomenon in humans. This system controls the temperature of the human body from its normal temperature to the lowest temperature set-node or, on the other hand, to the highest temperature set-node. Human beings' energy comes from the foods they consume. After these foods are digested, they are converted into power and heat to make vasodilation, working, and shivering for increasing temperature, and vasodilation, sweating, and evaporating for decreasing human body temperature.

The external influence is the ambient temperature, which changes all the time. This ambient temperature fluctuation could influence the body's skin temperature [23]. The human body's skin temperature is getting higher or lower. The more measurement nodes, the better the result. However, there are consequences. Multi-node measurement is energy— and time-consuming, making it unrealistic for massive measurement applications such as COVID testing in an airport.

Our preliminary study showed no significant differences between the 16-node and eight-node methods [24]If we want to investigate the human body, not a particular point of the body, why should we spend our effort utilizing the 16-node that can be replaced with the eight-node with the same quality level? The impact of the preliminary study result triggers the authors to drastically reduce the multi-node methods to their minimum number but with the same accuracy level.

This study aimed to obtain a technique to develop two-node methods as accurate as multi-node methods for human body temperature measurement applications. If it works well, this finding can reduce the multi-node temperature measurement number on a human body to its minimum number, namely two. Besides, this finding may also prevent the utilization of invasive methods. Invasive methods are hurting. If it is reliable, non-invasive methods for measuring body temperature are essential for diagnosing and monitoring infectious diseases. The reliability of this study technique is tested by comparing the two-node method with the previous study that used the 16-node temperature measurement method.

II. Materials and Method

A. Multi-Node Method

At present, there are many multi-node methods. These methods are one-dimensional, two-dimensional, and three-dimensional human body temperature measurements. A one-dimensional measurement means that the human body is divided into sections. For two-dimensional measurements, each section is divided into subsections. Every subsection is further divided into subsubsections in three-dimensional measurements. Only some of the multi-node methods are presented in Table 1.

The one-dimensional (longitudinal side) human body temperature measurement comprises many methods, such as 128-node and three-node methods. The three-point methods include many techniques, such as the three-measuring point model.

TABLE I
SOME MULTI-NODE METHODS

No	Method	Node	Description
One-Dimensional Measurements			
1	3-point model	3	1. chest, 2. forearm, and 3. calf [25]
2	Ra4 point model	4	1. chest, 2. upper arm, 3. thigh, and 4. calf [25]
3	Ne4 point model	4	1. chest, 2. forearm, 3. thigh, and 4. calf [25]
5	5-point model	5	1. chest, 2. abdomen, 3. lumbar, 4. upper arm, and 5. thigh [25]
6	6-point model	6	1. cheek, 2. chest, 3. lumbar, 4. forearm, 5. hand, and 6. thigh [25]
7	Core and seven measuring site model	8	1 node for core + 7 nodes for skin 1. A (bridge of the nose), 2. E (front waist.), 3. F (lower arm), 4. G (hand), 5. H (quadriceps), 6. J (shinbone), & 7. K (feet) [26]
8	8-point model	8	1. cheek, 2. neck, 3. chest, 4. lumbar, 5. thigh, 6. calf, 7. forearm, and 8. upper arm [25]
9	Core and 15-measuring site model	16	1 node for core + 15 nodes for skin 1. A (bridge of the nose), 2. B (upper cheek), 3. C (chest), 4. D (upper arm), 5. E (front waist.), 6. F (lower arm), 7. G (hand), 8. L (nape of the neck), 9. M (shoulder blade), 10. N (back waist), 11. H (quadriceps), 12. P (hamstring), 13. J (shinbone), 14. Q (calf), & 15. K (feet) [26]

No	Method	Node	Description
One-Dimensional Measurements			
10	Nilsson model	17	1. foot right, 2. foot left, 3. calf right, 4. calf left, 5. thigh right, 6. thigh left, 7. hand right, 8. hand left 9. lower arm right, 10. lower arm left, 11. upper arm right, 12. upper arm left 13. upper back, 14. chest 15. face, 16. scalp, and 17. torso [27]
11	34-zone Newton thermal manikin	34	1. face, 2. head, 3. right upper arm front, 4. right upper arm back, 5. left upper arm front, 6. left upper arm back, 7. right forearm front, 8. right forearm back, 9. left forearm front, 10. left forearm back, 11. Right Hand, 12. Left hand, 13. upper chest, 14. Shoulders, 15. Stomach, 16. Mid back, 17. Waist, 18. Lower back, 19. right upper thigh front, 20. right upper thigh grd. 21. Right upper thigh back, 22. left upper thigh front, 23. left upper thigh grd. 24. left upper thigh back, 25. right lower thigh front, 26. right lower thigh back, 27. left lower thigh front, 28. left lower thigh back, 29. right calf front, 30. right calf back, 31. left calf front, 32. left calf back, 33. right foot, 34. left foot [28]
12	Avolio multi-branched model	128	1. head (26 nodes), 2. chest (33 nodes), 3. pelvis (19 nodes), 4. left upper arm (7 nodes), 5. left fore arm (5 nodes), 6. left hand (1 node), 7. left thigh (4 nodes), 8. left calf (6 nodes), 9. left foot (2 nodes), 10. right upper arm (7 nodes), 11. right fore arm (5 nodes), 12. right hand (1 node), 13. right thigh (4 nodes), 14. right calf (6 nodes), and 15. right foot (2 nodes) [18]
Two-Dimensional Measurements			
13	Individualized thermoregulatory model	36	9 segments (1. head, 2. chest, 3. waist, 4. upper arm (unilateral), 5. forearm (unilateral), 6. hand (unilateral),7. thigh (unilateral) , 8. lower leg (unilateral) , 9. foot (unilateral)) x 4 layer (1. core, 2. muscle, 3. fat, 4. skin) [29]
14	Multi-segmented model	60	15 segments (1. head, 2. chest, 3. back, 4. left upper arm, 5. right upper arm, 6. left arm, 7. right arm, 8. left hand, 9. right hand, 10. left thigh, 11. right thigh, 12. left leg, 13. right leg, 14. left foot, 15. right foot) x 4 layers (1. core, 2. Muscle, 3. fat, and 4. skin) [30]
15	65-node thermoregulation model	65	16 segments (1. head, 2. chest, 3. back, 4. pelvis, 5. left shoulder, 6. right shoulder, 7. left arm, 8. right arm, 9. left hand, 10. right hand, 11. left thigh, 12. right thigh, 13. left leg, 14. right leg, 15. left foot, and 16. right foot) x 4 layers (1. core, 2. muscle, 3. fat, and 4. skin) + 1 clothing= 65 nodes [9]
16	Thermoregulation model JOS-3	85	1. head (6), 2. Neck (4), 3. chest (5), 4. back (4), 5. pelvis (6), 6. left (L)-shoulder (5), 7. L-arm (5), 8. L-hand (5), 9. right (R)-shoulder (5), 10. R-arm (5), 11. R-hand (5), 12. L-thigh (5), 13. L-leg (5), 14. L-foot (5), 15. R-thigh (5), 16. R-leg (5), and 17. R-foot (5) [31]
Three-Dimensional Measurements			
17	Wissler model	5061	21 elements x (((14 radial nodes of tissue + 6 radial nodes of clothing) x 12 angular segments)+1 radial nodes of tissue))) [32]
18	Extant Wissler model	6300	25 elements x 21 concentric cylindrical shells x 12 angular segments [33]
19	Thermoregulatory model	13446	15 elements [34]

The two-dimensional (longitudinal and radial side) human body temperature measurement uses the human body surface and the inside or concentric cylinder part of the human body. This measurement makes the measurement system more complex, and someone who is measured is inconvenient.

The three-dimensional (longitudinal, radial, and angular) human body temperature measurement integrates the concentric angular side into the two-dimensional human body temperature measurement. The body surface is measured circularly from the front side to the back, right, and left sides. In the Extant Wissler model, the temperature measurement points can reach 6300 points (25 elements x 21 concentric cylindrical shells x 12 angular segments) [33].

B. 16-Node Method

There are some 16-node methods for human body temperature measurements. One is the core and 15-measuring site model [26] This study used this method because it continues the authors' previous study. Hence, it also uses the previous research to make the results comparable. The data were taken from body temperature measurements of seven married couples.

The core and 15-measuring site model methods are divided into the core and the skin. The core can be located on the body surface (axilla and forehead) and natural body orifices (rectum, mouth, ear canal, esophagus, nasopharynx, and gastro-intestinal) [11]. The ear canal (tympanic) was chosen to represent the core because this point is the most common and comfortable point for all seven married couples. The core temperature minimum contributes to 80 % of the total body temperature.

The skin points are 1. A (bridge of the nose), 2. B (upper cheek), 3. C (chest), 4. D (upper arm), 5. E (front waist.), 6. F (lower arm), 7. H (hand), 8. L (nape of the neck), 9. M (shoulder blade), 10. N (back waist), 11. H (quadriceps), 12. P (hamstring), 13. J (shinbone), 14. Q (calf), & 15. K (feet) [26]. The skin temperature that maximum contributes to 20 % of the total body temperature is divided by 15 points. The Werner method makes the difference between the right and the left sides optional. The used side in this study is uniform on the left side because all heart-married couples are right-handed, and the left forearm (upper arm) is nearer to the heart as the center of blood.

The human body temperature, based on the core and 15-measuring site model, can be presented as follows:

$$T_{mean\ body} = 0.8T_{core} + 0.014\frac{(A+B+L)_{head}}{3} + 0.028\frac{(D+F)_{arms}}{2} + 0.01G_{hands} + 0.07\frac{(C+E+M+N)_{trunk}}{4} + 0.038\frac{(H+P)_{thigh}}{2} + 0.026\frac{(J+Q)_{calf}}{2} + 0.014K_{feet} \quad (1)$$

C. Two-Node Method

Heat balance in a human being can be represented as:

$$M - W = S + q_{sk} + q_{res} = (S_k + S_{cr}) + (C + R + E_{sk}) + (C_{res} + E_{res}) \quad (1)$$

where M= heat due to metabolic rate, W= heat due to mechanical work done by the human body, S= heat storage rate of the human body, S_{sk}= rate of heat storage in the skin compartment, S_{cr}= rate of heat storage in the core compartment, q_{sk}= total rate of heat loss from the skin; q_{res}= total rate of heat loss through respiration; C + R= sensible heat loss from the skin; C= convection heat exchange, R= environmental radiation calorific value, E_{sk}= the evaporative heat flow at the skin, C_{res}= respiratory convective heat flow, E_{res}= respiratory evaporative heat flow [35].

Conduction is used for heat transfer to the adjacent layers and circulation to skin surfaces[29]. Hence, the sensible heat loss from the skin should be completed with K, the conduction heat exchange,

$$S = M \pm W \pm R \pm C \pm K - E \quad (3)$$

where E= evaporative heat dissipation is the addition of E_{sk} and E_{res}. This equation is sometimes equipped with the shivering component (S_h) in cold temperatures [36].

Thermoregulation is the ability of an organism to maintain normothermia [37] or a system in the human body to make it homeostatic or warm-blooded. This system allows the human body to adjust its metabolic rate to maintain equal heat production and loss [21]. This system is determined by source and sink. The source is the controlling (active) element, and the sink is the controlled (passive) element.

The two-node method for human body measurements uses these variables to decide the human body temperature. The controlling element is called the core, while the controlled element is called the skin [38]. A study showed that under steady hot and cold exposures, the maximum deviation in the core temperature is 0.30 °C and the mean skin temperature is 0.60 °C [39]. Hence, the thermoregulation can be represented at least by two points.

The core maintains a deep core temperature in a narrow range of 36.8 ˚C for thermal comfort and health[34] and the source of heat energy transfer to the body via vasodilation, vasoconstriction, sweating, and shivering. The energy comes from food energy conversion into heat or works through food digestion. Hungry or satisfied, detected by the hypothalamus, triggers someone to digest food. That is why the human body's core temperature should be the hypothalamus. However, the hypothalamus is an internal organ accessed for temperature measurements. Hence, many other points are assumed to represent the core temperature in the human body, such as the rectum. The authors chose the core temperature at the ear canal due to accuracy and standard convenience for temperature measurement. This core is the same as the core of the compared 16-node method.

The skin is anywhere on the body surface that is not categorized as the core. It is used for heat transfer mechanisms in the body [40] and to the outside world. It is responsible for about 90% of heat loss by four mechanisms: radiation, evaporation, convection, and conduction [21]. In this study, the human body is one of 15 points used by the compared 16-node method. Which point is used for the two-node method is decided by the testing result between the two-node method and the 16-node method.

D. Condensed Multi-Node Method

There are some steps to simplify the multi-node method to its minimum number (two-nodes, condensed multi-nodes). In this study, the authors used 16 nodes as an example of a multi-node method because the authors have used this 16-node method for the previous study. The 16-node formula presented in formula one is condensed into the two-node method as follows:

$$T_{mean\ body} = 0.8T_{core} + 0.2T_{skin} \quad (4)$$

The sampling data was collected for every member. In this study, there are seven male and seven female members. Every member was measured ten times, so there were 16 x 10 (160) samples for each member. The ten repetitions were averaged, and 16 data were left for every member.

The multi-node method's measurement data should be classified as the core and skin temperatures. There was only one core node. The core data was the average of seven married couples (seven males and seven females). This core node (X_c) was used as the core for the two-node and 16-node methods. The rest of the data was skin data. Hence, there are 15 average skin nodes for every member. The data for males, females, and seven married couples were averaged.

The average of all seven married couples at every node was multiplied by their weight. For example, the skin data at skin A, according to Formula 1, is multiplied by 0,014. All skin data are collected (X_{15}). The X_{15} is then compared with one of the skin data. Choose one of the closest skin values to X_1. Use this node as a representation of the skin data (X_1).

The core (X_c) and the skin data of the 16-node method (X_{15}) are integrated using Formula 4 to form (X_{16}). On the other hand, the core (X_c) is also added with the representation of the skin data (X_1) to create the body temperature of the two-node method (X_2) as presented in Formula 4; the X_2 and X_{16} are then tested.

E. Level Equality Testing

The X_2 and X_{16} are tested by comparing the mean of both methods using two-way ANOVA (Analysis of Variance) with Repetition. To make a more detailed comparison between the two methods, gender and the interaction between method and gender are also tested. Method results between 16-node and two-node methods are tested. The male and female data is summed up first before the testing. This testing is formulated in Hypothesis 1. Namely, there is a significant difference between the 16-node and two-node methods.

Data for both genders are also compared. Data from both methods are summed up for every gender type. The hypothesis for this testing is Hypothesis 2, which mentions no significant difference between genders. In the factor interaction step, all data are classified into four clusters. Cluster 1 comprised the intersection data between the 16-node method and the male; Cluster 2 comprised the intersection data between two core methods and the male; Cluster 3 comprised the intersection data between the 16 core method and the female; and Cluster 4 comprised the intersection data between the 2 core methods and the female. Hypothesis 3 for this testing expresses no interaction between method and gender.

The hypotheses are tested using the F test, namely, if

$$F_0 > F_{0.05;\,DF;\,DFW} \tag{5}$$

then the hypothesis is rejected, and if:

$$F_0 \leq F_{0.05;\,DF;\,DFW} \tag{6}$$

then the hypothesis is accepted.

These tests are valid for three hypotheses. The $F_{0.05;\,DF;\,DFW}$ is the theoretical F for the significant level of 0.05. In this case, DF was 1, while DFW was 24. The value of $F_{0.05;\,DF;\,DFW}$ can be obtained from the F distribution table at the related DF (degree of freedom). The F_0 is the empirical F, where there were three F_0 in this case, the F for the method (F_A), the F for gender (F_B), and the F for the method and gender interaction (F_{AB}). A detailed method for ANOVA testing can be obtained from the previous study. This testing is essential in this study because the two-node model needs better calculation accuracy [41]. This testing helps guarantee that the selected two-node method is as accurate as the multi-node method.

III. Result and Discussions

A. Findings

The authors used our previous study data to reduce the errors in comparing the two-node human body temperature measurement method and the 16-node human body temperature measurement method. One error was the sampling error, which came from the same data source. Hence, the sampling data error was omitted.

The human body temperature measurement data were classified into male (Table 2) and female (Table 4) groups. Each group comprises seven members (personnel or samples). Each member had two kinds of human body temperature measurements: the core and the skin temperature measurement node. In order to make apple-to-apple comparison results with the author's previous study, the core of the body in this study was the ear canal, while the skin temperature measurements were 15 nodes (A, B, L, D, F, G, C, E, M, N, H, P, J, Q, and K). Each node was averaged. Hence, the seven rows in Table 2 could be simplified as one row, the average (M_a in Table 3). Applying formula 1, the Ma for skin measurement was 20 %, while the core measurement was 80 %. The results were placed in the M_w row of Table 3. Next, each skin-weighted result was added to the core result. The summation was presented in the M_m row in Table 3. The M_m row showed the temperature measurement for the ear canal and D node. Hence, there were 15 kinds of two-node measurements.

The above step was repeated for the female group. Equal to the male group, the female group also had 15 kinds of two-node measurements (Table 5). Therefore, there were two temperature measurement results: the male result (Mm), as presented in Table 4, and the female temperature result (F_m), as presented in Table 5.

The M_m and F_m, then, were averaged. These averages were two-node measurement results (Table 6). There were 15 two-nodes of temperature measurements results as a combination between the core node (ear canal) and a skin node, whether it was A, B, L, D, F, G, C, E, M, N, H, P, J, Q, or K. Which skin node could best represent the weighted average of 15 skin node? We would compare these nodes with the 16 nodes of temperature measurement results. The best node was where it had the nearest value to the average of the 16-node measurement result. The 16-node temperature measurement result of the human body was obtained beforehand and processed using Formula 1. The average result of 16-node measurements for males and females was 36.89 and 36.68, respectively. The average temperature was 36.785.

The average temperature measurement results for the two-node method were near 36.785 and 36.78 and 36.79. The value 36.78 was the result of the combination of the ear canal and the D (upper arm) node, while 36.79 was the result of the combination between the ear canal and the F (lower arm) node. So, 36.78 or 36.79 was chosen as a two-node measurement method? We have to analyze these choices first.

TABLE II
THE AVERAGE OF 10 TIMES TEMPERATURE MEASUREMENT RESULTS FOR EACH MALE MEMBER

	Temperature Measurement Nodes															Ear Canal
	A	**B**	**L**	**D**	**F**	**G**	**C**	**E**	**M**	**N**	**H**	**P**	**J**	**Q**	**K**	
M1	36.04	36.20	35.15	36.21	35.88	36.07	35.65	36.12	35.45	35.71	35.88	36.33	35.25	36.07	35.49	37.91
M2	35.16	36.01	36.14	36.42	35.45	36.09	35.31	35.49	35.62	35.13	34.42	34.28	34.90	34.46	34.21	38.04
M3	36.16	35.48	36.17	34.23	35.28	35.96	33.98	34.32	35.23	33.98	35.25	34.03	34.52	34.12	34.04	37.80
M4	36.32	35.92	35.42	35.07	35.66	37.38	35.14	34.64	33.79	33.73	35.53	33.74	33.82	34.12	33.98	37.06
M5	36.16	34.95	34.78	33.19	33.67	34.32	33.52	33.67	33.26	33.71	33.98	32.93	34.15	33.62	33.93	37.47
M6	35.58	35.79	34.31	34.24	35.58	36.79	34.46	34.26	33.55	34.02	35.27	35.11	35.36	35.20	34.57	36.84
M7	36.48	36.33	35.17	35.67	34.51	34.09	34.86	35.47	34.68	35.65	34.87	35.05	34.93	34.03	34.43	36.58

TABLE III
THE AVERAGE TEMPERATURE MEASUREMENT RESULTS FOR ALL MALE MEMBER

	Temperature Measurement Nodes															Ear Canal
	A	**B**	**L**	**D**	**F**	**G**	**C**	**E**	**M**	**N**	**H**	**P**	**J**	**Q**	**K**	
Ma	35.99	35.81	35.31	35.00	35.15	35.81	34.70	34.85	34.51	34.56	35.03	34.50	34.70	34.52	34.38	37.39
Mw	7.20	7.16	7.06	7.00	7.03	7.16	6.94	6.97	6.90	6.91	7.01	6.90	6.94	6.90	6.88	29.91
Mm	37.11	37.07	36.97	**36.91**	36.94	37.07	36.85	36.88	36.81	36.82	36.91	36.81	36.85	36.81	36.78	+D

TABLE IV
THE AVERAGE OF 10 TIMES TEMPERATURE MEASUREMENT RESULTS FOR EACH FEMALE MEMBER

	Temperature Measurement Nodes															Ear Canal
	A	**B**	**L**	**D**	**F**	**G**	**C**	**E**	**M**	**N**	**H**	**P**	**J**	**Q**	**K**	
F1	36.40	34.93	35.78	35.33	35.23	36.54	36.20	36.51	36.42	34.69	34.92	34.56	34.45	34.49	35.25	37.47
F2	35.12	34.31	36.72	35.41	34.66	35.19	36.35	36.30	35.83	35.81	34.56	35.13	35.25	33.80	35.92	36.96
F3	35.73	34.74	35.42	34.03	34.46	35.18	34.39	35.04	34.34	33.54	33.86	33.36	34.74	32.94	33.02	36.74
F4	36.61	35.48	35.15	35.16	35.22	35.45	35.24	34.69	34.67	34.89	33.84	33.70	34.53	33.22	35.18	37.60
F5	36.33	35.28	34.09	35.84	35.81	36.17	36.34	36.08	36.30	35.87	36.33	35.05	35.74	35.39	33.61	37.67
F6	36.07	35.12	36.16	34.55	34.54	35.70	35.56	34.79	35.02	34.75	34.06	34.86	34.05	33.32	33.90	36.91
F7	35.02	34.64	35.23	34.74	34.97	34.90	36.09	37.06	35.38	35.16	35.51	34.00	34.12	33.84	33.41	36.12

TABLE V
THE AVERAGE TEMPERATURE MEASUREMENT RESULTS FOR ALL FEMALE MEMBER

	Temperature Measurement Nodes															Ear Canal
	A	**B**	**L**	**D**	**F**	**G**	**C**	**E**	**M**	**N**	**H**	**P**	**J**	**Q**	**K**	
Fa	35.90	34.93	35.51	35.01	34.98	35.59	35.74	35.78	35.42	34.96	34.73	34.38	34.70	33.86	34.33	37.07
Fw	7.18	6.99	7.10	7.00	7.00	7.12	7.15	7.16	7.08	6.99	6.95	6.88	6.94	6.77	6.87	29.65
Fm	36.83	36.64	36.76	**36.66**	36.65	36.77	36.80	36.81	36.74	36.65	36.60	36.53	36.59	36.43	36.52	

TABLE VI
THE AVERAGE TEMPERATURE MEASUREMENT RESULTS FOR ALL MEMBER

	Temperature Measurement Nodes															Ear Canal
	A	**B**	**L**	**D**	**F**	**G**	**C**	**E**	**M**	**N**	**H**	**P**	**J**	**Q**	**K**	
Tm	36.97	36.86	36.86	**36.78**	36.79	36.92	36.83	36.84	36.77	36.73	36.76	36.67	36.72	36.62	36.65	36.97

The measurement value of 36.78 was a better choice than 36.79 for two reasons. First, the results for two nodes at the ear canal and D and the pair of the ear canal and F were rounded at two digits behind the node. If they were rounded at four digits, then the results were not 36.78 and 36.79 but were 36.7824 and 36.7943. The result of 36.7824 was nearer to 36.785 than 36.7943 to 36.785.

Second, the Mm and Fm for D are better than the F nodes. The Mm for D is 36.91, and for F, 36.99, while the Fm for D was 36.66, and for F, 36.65. The value of 36.91 was nearer to 36.89 than 36.99 to 36.89. The value of 36.66 was closer to 36.68 than 36.65 to 36.68.

Immediately, the ear canal and D node pairs gave better results than the other node pairs. However, this best node pair's temperature should not significantly differ from the human body temperature of the 16-node temperature measurement mode. This significant difference should be specifically tested using two-way ANOVA with Repetition.

B. Testing of Findings

To obtain an accuracy level comparison between the two-node temperature measurement method and the 16-node temperature measurement method, we could determine the accuracy of both methods by comparing their measurement results. The closer their results are, the more equal their accuracy.

The 16-node temperature measurement method was accurate. It was derived from the thermoregulation concept, where there were source and sink. The source (the core) temperature was more stable than the sink (skin temperature). Theoretically, many disturbances to skin temperature stability, such as ambient temperature, skin color, and the used coat, were present. Many nodes represented the 16-node temperature measurement method weighed around the human body. Hence, this method was holistic and entirely accurate.

Suppose the result of the two-node temperature measurement method was relatively similar to the 16-node temperature measurement method. In that case, the accuracy of the two-node temperature measurement method was at the level of the 16-node temperature measurement method. This comparison would be tested in three hypotheses: no significant differences between method and gender and no interaction between method and gender.

For the hypothesis testing, the first step was to average every member for 16-node and two-node temperature measurement method results (Table 7). Attention should be paid to the fact that there were some rounded corners in the table.

TABLE VII
THE DATA SUMMARY FOR METHOD, GENDER, AND THEIR INTERRELATION TESTING

M/F Member	16-Node X_{m1}	16-Node $(X_{m1})^2$	2-Node X_{m2}	2-Node $(X_{m2})^2$	Summation $\sum_{n=1}^{n=2} x_n$	Summation $\sum_{n=1}^{n=2} (x_n)^2$
1	37.50	1405.98	37.57	1411.51	75.07	2817.48
2	37.46	1403.47	37.72	1422.50	75.18	2825.97
3	37.17	1381.42	37.09	1375.37	74.25	2756.79
4	36.59	1338.99	36.66	1344.10	73.25	2683.10
5	36.72	1348.69	36.61	1340.59	73.34	2689.27
6	36.43	1327.44	36.32	1319.14	72.75	2646.59
7	36.26	1314.78	36.40	1324.81	72.66	2639.59
$\sum_{m=1}^{m=7} x_m$	258.14	9520.78	258.37	9538.02	516.50	19058.80
8	37.06	1373.13	37.04	1372.11	74.10	2745.24
9	36.65	1342.93	36.65	1343.22	73.30	2686.15
10	36.22	1311.82	36.20	1310.30	72.42	2622.11
11	37.02	1370.32	37.11	1377.30	74.13	2747.62
12	37.28	1389.49	37.30	1391.59	74.58	2781.08
13	36.47	1329.71	36.44	1327.73	72.90	2657.44
14	35.90	1288.59	35.84	1284.79	71.74	2573.38
$\sum_{m=8}^{m=14} x_m$	256.58	9405.99	256.59	9407.04	513.16	18813.02
$\sum_{m=1}^{m=14} x_m$	514.71	18926.77	514.95	18945.05	1029.67	37871.82

The ANOVA table for the significant level 0.05, DF= 1, and DFB= 24 was 4.26. This theoretical F value worked for the three hypotheses. F_o for method, gender, and interrelation between method and gender were calculated as 0.00803, 1.55629, and 1,5709, respectively. Every result was less than the theoretical value. Hence, every hypothesis was accepted.

The Wireless Body Area Network (BAN) is a sensing technology that can be continuously worn via a wireless network on the patient's body[42] and is an excellent medium to apply this study's findings. Briefly, BAN is a healthy instrument. It uses body sensors to collect and evaluate body parameters such as temperature from many patients so that the hospital officers can give each patient the correct healthcare. The complexity of the BAN is proportional to the number of patients. Hence, it is essential to simplify the measurement method, as was carried out in this study, if it remains at the same or has an insignificant accuracy level.

C. Further Development

So far, the comparison has been successfully conducted for the 16-node method, which is categorized as a one-dimensional measurement method. Meanwhile, the thermoregulation theory has been developing. Hence, the temperature measurement methods have developed into two- and three-dimensional methods. Hence, it is challenging for further development to compare the results of two condensed methods with these two- or three-dimensional methods. Let us see its possibility.

Formula 1 and Formula 4 show that skin affects only 20 % of the final temperature measurement. For this reason, using some steps, the multi-node method can be condensed into a two-node method.

First, the results of the human body temperature measurement are split into core and skin data. Use the core data of the multi-node method as the core for the two-node method. The remaining data is categorized as skin data. Second, the average skin data in the multi-node method would be obtained using the formula for that method. The formula for each method might be different. In this step, the average skin data is called the skin data for the multi-node method. Third, select the skin node with a value equal to or almost equal to the average skin data. If some nodes fulfill the criteria, please choose the most comfortable node to measure. The selected skin data in this step is called the skin data for the two-node method. Fourth, add the core and skin data. The addition between the core data in Step 1 and the skin data in Step 2 is called the body temperature for the multi-node method, and the addition between the core data in Step 1 and the skin data in Step 3 is called the body temperature for the two-node method. Fifth, test the temperature equity of the multi-node method and the two-node method. If there is a significant difference between them, they are at the same accuracy level. Although it is beneficial to reduce unnecessary efforts, this two-node (condensed multi-node) method is limited. It cannot be used to obtain a certain temperature organ on certain occasions. A multi-node method, such as a 3-D virtual human thermoregulatory model, for example, can observe the variation in organ temperature during heat stress [43].

IV. Conclusions

There were no significant differences between the 16-node method and the condensed multi-node (two-node) method, male and female, and no significant interaction between the method and gender. As a consequence of these findings, we can reduce the 16 nodes into two nodes. Higher-node methods might also be substituted with the two-node method, but it has yet to be proven in this study. Further study is needed, especially for the two or three-dimensional methods.

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