Journal of Multidisciplinary Engineering Science Studies (JMESS)
ISSN: 2458-925X
Vol. 8 Issue 2, February - 2022

Model Optimization And Evaluation Of Iot Body Temperature Measuring Device Datasets Using Paired-Difference T-Test Approach

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***Abstract*— In this paper, model optimisation and evaluation of IoT body temperature measuring device datasets using paired-difference t-test approach is presented. Specifically, the paper considered two sets of body temperature datasets captured at the same time using the IoT Body Temperature Measuring (IoTBTM) device and the Body Infrared Thermometer DJ-8861 (BIT-DJ-8861) device. The IoTBTM device also captures the ambient temperature at the same time with the body temperature. The original dataset was split into, the positive net temperature dataset (for the IoTBTM device measured body temperature values that are greater than the IoTBTM device measured ambient temperature) and the negative net temperature datasets (for the IoTBTM device measured body temperature values that are less than the IoTBTM device measured ambient temperature). The paired-difference t-test was conducted on the positive net temperature dataset and also on the negative net temperature dataset. Furthermore, cubic regression model was developed to optimise the measurement accuracy of the IoTBTM device with respect to the reference BIT-DJ-8861) device. The paired-difference t-test results show that for the positive net temperature dataset the training dataset sample mean error before the model was applied was 0.0520 and after the model was applied the sample mean error had reduced to 0.0026. Also, paired-difference t-test results show that for the negative net temperature dataset the training dataset sample mean error before the model was applied was 1.2025 and after the model was applied, the sample mean error had reduced to 0.0034. The results showed that the model effectively minimized the error in the studied measured body temperature datasets. Essentially, the is suitable for optimizing the measurement accuracy of the IoTBTM device with respect to the reference body temperature measuring device, which in this study is Body Infrared Thermometer DJ-8861 device.**

Keywords*— Model optimisation, IoT Body Temperature Measuring Device, Body Temperature Measuring Device, Paired-difference t-test Approach, Body Infrared Thermometer DJ-8861

1. Introduction

An Internet of Things (IoT) body temperature measuring (IoTBTM) device is a device that is equipped with temperature sensors, microcontroller, Internet connectivity capability and relevant firmware and software that enable it measure the body temperature, process, store, and communicates the body temperature data to a web-based storage server [1,2,3]. In addition, the IoTBTM device presented in this paper also has sensor for capturing the ambient temperature which can be used to assess the effect of ambient temperature on the measured body temperature [4,5,6]. The main focus of this paper is to calibrate the IoTBTM device body temperature readings using the Body Infrared Thermometer DJ-8861 which is commonly used in the hospitals for body temperature measurement [7,8,9,10].

Particularly, in this paper, a model is developed based on empirically measured paired body temperature samples which were obtained from a set of patients using the IoTBTM device and the Body Infrared Thermometer DJ-8861. The model takes input from the IoTBTM device body temperature reading and then generates predicted body temperature value that would have been obtained if the measurement was conducted using the Body Infrared Thermometer DJ-8861. The paired-difference t-test analysis was conducted n the model on the model predicted body temperature values and the actual body temperature values obtained using the Body Infrared Thermometer DJ-8861

[11,12,13,14,15]. Essentially, the model is used to tune the IoTBTM device body temperature measurement to be as close as possible to the reference equipment, which in this cse is the Body Infrared Thermometer DJ-8861.

2. Methodology

The paper considered two sets of body temperature datasets captured at the same time using the IoT Body Temperature Measuring (IoTBTM) device and the Body Infrared Thermometer DJ-8861 (BIT-DJ-8861) device. The IoTBTM device also captures the ambient temperature at the same time with the body temperature. The original dataset was further split into, the positive net temperature (for the IoTBTM device measured body temperature values that are greater than the IoTBTM device measured ambient temperature) and the negative net temperature datasets (for the IoTBTM device measured body temperature values that are less than the IoTBTM device measured ambient temperature). The paired-difference t-test was conducted on the positive net temperature dataset and also on the negative net temperature dataset.

In order to improve on the measurement accuracy displayed from the IoTBTM device measured body temperature values, an analytical model was developed to predict the BIT-DJ-8861 device measured body temperature value from each IoTBTM device measured body temperature value. Again, paired-difference t-test was conducted on the model predicted positive net temperature dataset and also on the model predicted negative net temperature dataset. Essentially, the model fitting is used to calibrate the IoTBTM device so that its measured value final output after the calibration with the model is performed will be more accurate with respect to the reference BIT-DJ-8861 body temperature measuring device.

1) 2.1 The analytical expressions for the paired-difference t-test approach

Let the body temperature that are measured with the Body Infrared Thermometer DJ-8861 device be represented as $T_{S,k}$ for and the body temperature that are measured with the IoT Body Temperature Measuring (IoTBTM) device be represented as $T_{R,k}$, where k = 1,2,3,…N. Then, the difference in the paired data items, denoted as $D_{SR,k}$ is expressed as;

$$D_{SR,k} = T_{S,k} - T_{R,k} \text{ for k = 1,2, 3,…N} \quad (1)$$

Let $\overline{D}$ denote the mean of $D_{SR,k}$, then;

$$\overline{D} = \frac{[\sum_{k=1}^{N}(D_{SR,k})]}{N} \quad (2)$$

Let S_D denote the standard deviation of $D_{SR,k}$, then;

$$S_D = \sqrt[2]{\left(\frac{\left[\sum_{k=1}^{N}(D_{SR,k}-\overline{D})^2\right]}{(N-1)}\right)^2} \quad (3)$$

Let SE_D denote the standard error of $\overline{D}$, then;

$$SE_D = \left(\frac{S_D}{\sqrt{N}}\right) \quad (4)$$

Let t_D denote the t_D t-statistic, then;

$$t_D = \frac{\overline{D}}{SE_D} \quad (5)$$

Let df denote the degree of freedom, then;

$$df = N - 1 \quad (6)$$

Let α denote the significance value, and let $t_{Dcritical}$ denote the critical t value, then;

$$t_{Dcritical} = t_{(\alpha/2)} \text{ at df} \quad (7)$$

Let $CI_{D\alpha}$ denote the confidence interval in respect of SE_D and α , then;

$$CI_{D\alpha} = \left[\left(\overline{D} - \left((t_{(\alpha/2)})(SE_D)\right)\right), \left(\overline{D} + \left((t_{(\alpha/2)})(SE)\right)\right)\right] \quad (8)$$

The result of the paired-difference t-test is considered to indicate that the mean of $T_{S,k}$ and $T_{R,k}$ are the same or that there is no significant difference in the mean of the two datasets when the value of t_D is such that;

$$\left(\overline{D} - \left((t_{(\alpha/2)})(SE_D)\right)\right) \leq \overline{D} \leq \left(\overline{D} + \left((t_{(\alpha/2)})(SE)\right)\right) \quad (9)$$

3.0 Calibration and evaluation of the positive net temperature dataset

The body temperature dataset for the positive net temperature category has a total of 73 data items which was split into 54 data records (74 % of the 73 data records) for model training, (as shown in Table 1 and Figure 1) and 19 data records (26 % of the 73 data records) for model validation , as shown in Table 2.

Table 1: The positive net temperature training dataset in degree centigrade

S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)	S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)	S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)
1	34.5	34.2	19	36.6	36.8	37	38.2	38.2
2	34.6	34.5	20	36.7	36.9	38	38.3	38.2
3	34.8	34.8	21	36.7	36.9	39	38.5	38.4
4	34.8	34.7	22	36.7	36.9	40	38.5	38.4
5	35	35.1	23	36.8	37	41	38.6	38.5
6	35	35.1	24	36.8	37	42	38.7	38.6
7	35.4	35.5	25	36.9	37.2	43	39	38.8
8	35.4	35.6	26	37	37.3	44	39	38.7
9	35.4	35.5	27	37.1	37.4	45	39.3	39
10	35.6	35.8	28	37.1	37.4	46	39.6	39.2

11	35.7	35.9	29	37.2	37.5	47	39.7	39.3
12	35.8	36	30	37.4	37.6	48	39.9	39.5
13	35.8	36	31	37.5	37.7	49	40	39.6
14	35.9	36	32	37.5	37.7	50	40.3	39.9
15	36	36.2	33	37.6	37.8	51	40.9	40.7
16	36.3	36.5	34	37.9	38	52	40.9	40.6
17	36.4	36.6	35	38	38.1	53	41.1	41
18	36.4	36.7	36	38.1	38.2	54	41.4	41.6

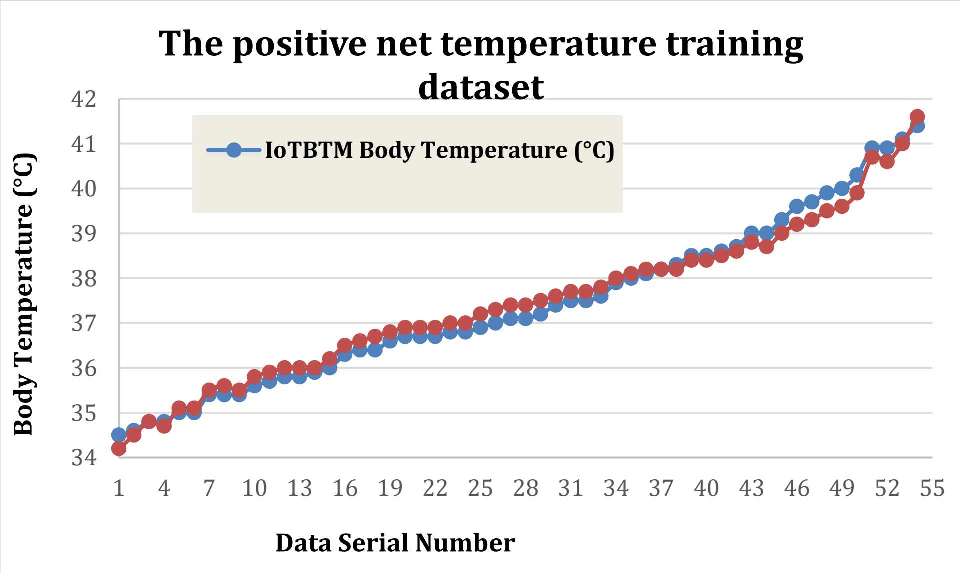

Figure 1: The scatter plot of IoTBTM measured body temperature (°C) and the BIT-DJ- measured body temperature (°C) for the positive net temperature training dataset

The paired-difference t-test with confident level at 95% was conducted for the **positive net temperature training dataset** and the results show that the lower and the upper point are -0.0594 and 0.05943 respectively with the sample mean of 0.0520 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 2.

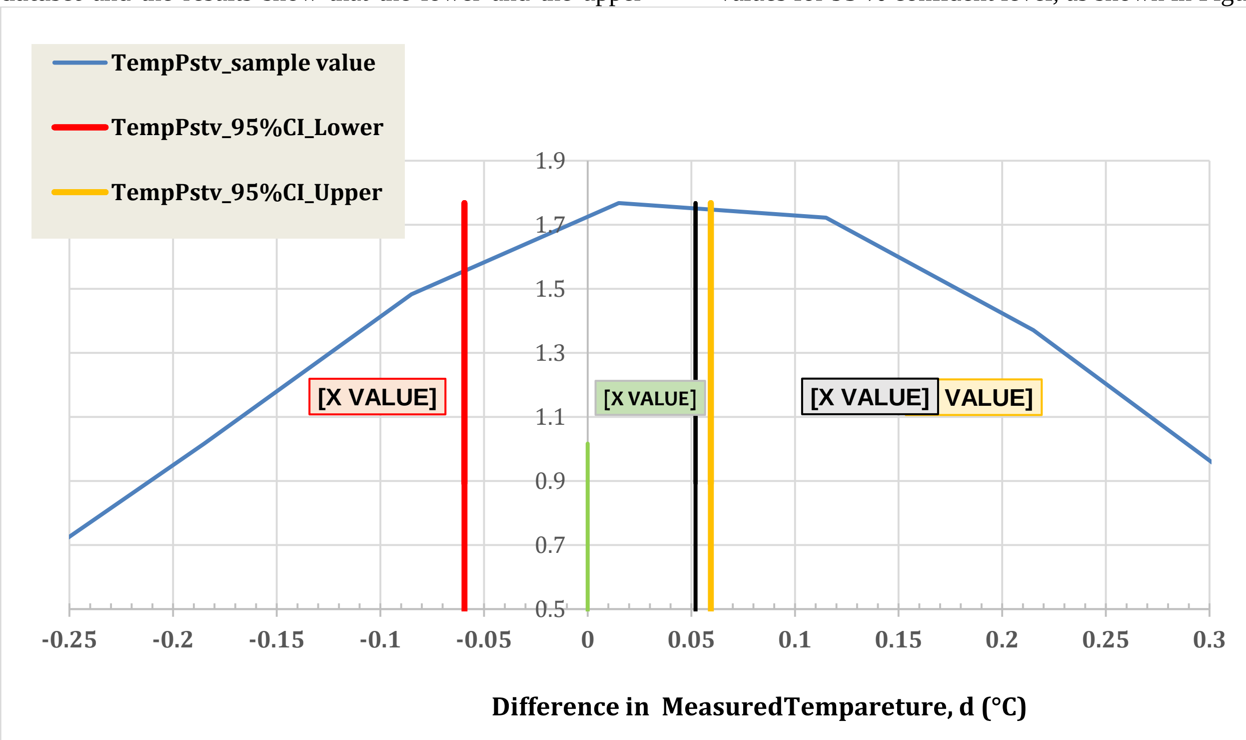

Figure 2: The graph of the paired-difference t-test result for the positive net temperature training dataset

Furthermore, based on the training dataset in Table 1, a regression model was developed in order to minimize the error between the IoTBTM device measured body temperature values and the BIT-DJ-8861 device measured body temperature values. The model in Equation 10 was developed using Microsoft excel solver tool. The model in Equation 10 was used for both positive net temperature training and validation datasets.

$$PDJ8861_k = 0.241(IoTBTM_k)^3 - 2.7145(IoTBTM_k)^2 + 102.63(IoTBTM_k) - 1264.6 \quad (10)$$

Where $PDJ8861_k$ is the kth predicted value of body temperature measurement with BIT-DJ-8861 device and ($IoTBTM_k$ is the kth body temperature measurement with the IoTBTM device.

The analytical model in Equation 10 was used to predict the expected value of body temperature measurement with BIT-DJ-8861 device from any given value of body temperature measurement with the IoTBTM device. The paired-difference t-test with confident level at 95% was conducted for the prediction of the **positive net temperature training dataset** and the results (in Figure 3) show that the lower and the upper point are -0.0218 and 0.0218 respectively with the sample mean of 0.0026 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 3. Also, it can be seen that the training dataset sample mean error before the model was applied was 0.0520 and after the model was applied, the sample mean error had reduced to 0.0026. This showed that the model effectively minimized the error in the training dataset.

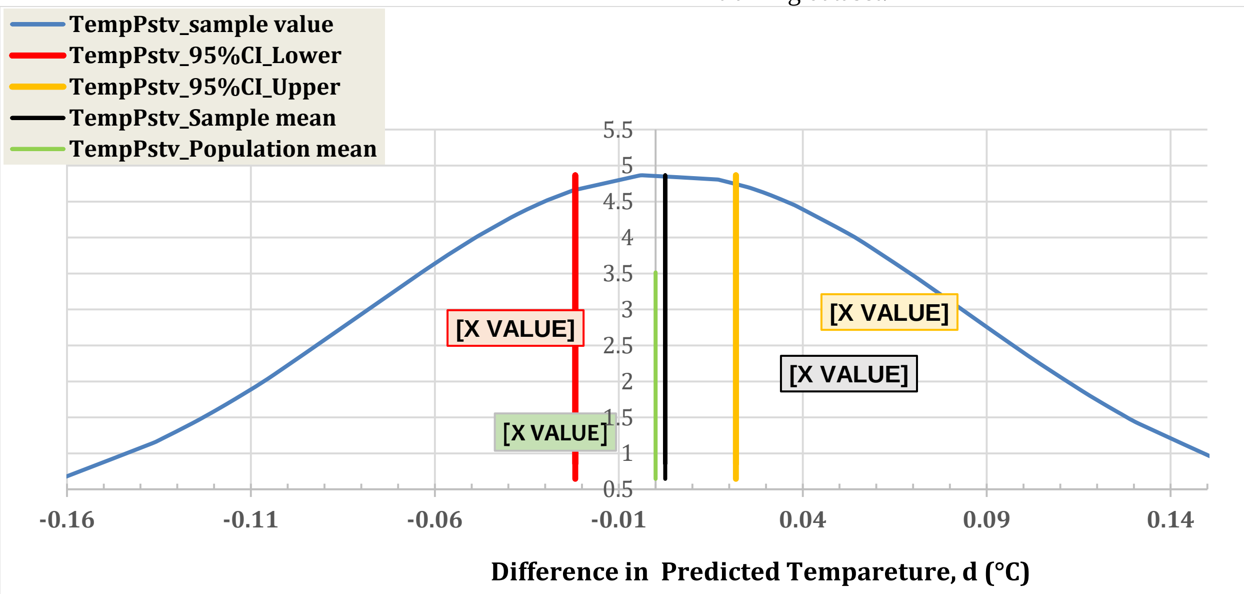

Figure 3: The graph of the paired-difference t-test result for the model optimised positive net temperature training dataset

Similarly, 26% of positive temperature data which represent 19 data records (**Table 2)** was used for cross validation of the optimisation model for the **positive net temperature training dataset**. The paired-difference t-test with confident level at 95% was conducted for the **positive net temperature cross validation dataset without the optimisation model** and the results (in Figure 4) show that the lower and the upper point are -0.1205 and 0.1205 respectively with the sample mean of 0.0097 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 4.

Similarly, the paired-difference t-test with confident level at 95% was conducted for the model predict **positive net temperature cross validation dataset** and the results (in Figure 5) show that the lower and the upper point are -0.0429 and 0.0429 respectively with the sample mean of -0.0029 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 5.

Also, it can be seen that the validation dataset sample mean error before the model was applied was 0.0097 and after the model was applied, the sample mean error had reduced to -0.0029. This showed that the model effectively minimized the error in the validation dataset as well.

Table 2: The positive net temperature validation dataset in degree centigrade

S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)	S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)	S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)
1	34.7	34.7	7	36.1	36.3	13	38.1	38.1
2	34.7	34.5	8	36.2	36.5	14	38.9	38.7
3	35.1	35.2	9	36.3	36.6	15	39.4	39.2
4	35.3	35.4	10	36.9	37.1	16	39.5	39.2

5	35.5	35.8	11	36.9	37.1	17	39.5	39.1
6	36	36.3	12	37.7	37.8	18	40	39.5
7	36.1	36.3	13	38.1	38.1	19	40.4	40

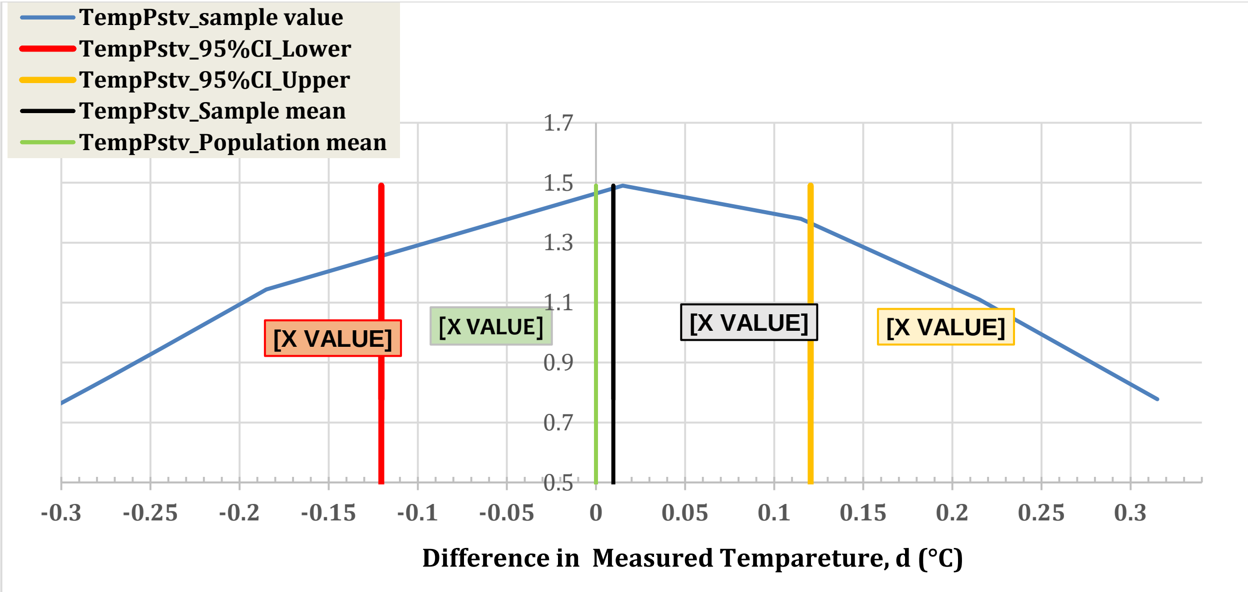

Figure 4: The graph of the paired-difference t-test result for the positive net temperature validation dataset

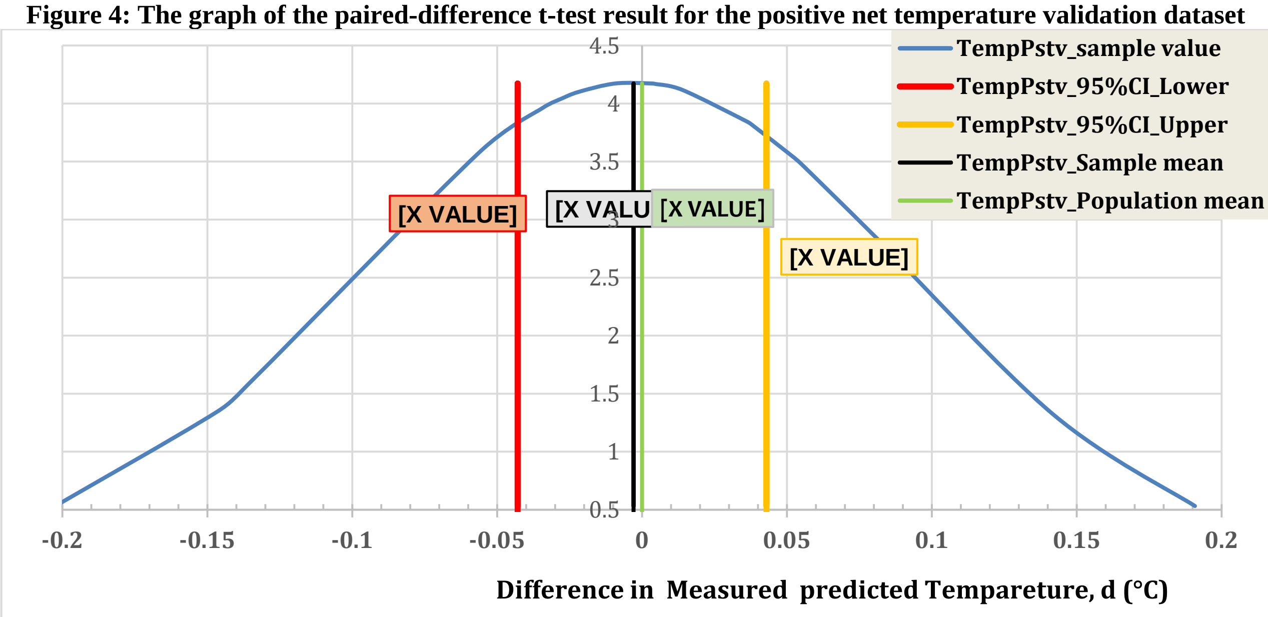

Figure 5: The graph of the paired-difference t-test result for the model optimised positive net temperature validation dataset

4. Calibration and evaluation of the negative net temperature dataset

The body temperature dataset for the negative net temperature category has a total of 73 data items which was split into 24 data records (77 % of the 31 data records) for model training, (as shown in Table 3 and Figure 6) and 7 data records (23 % of the 31 data records) for model validation , as shown in Table 4.

Table 3: The negative net temperature training dataset in degree centigrade

S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)	S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)
1	33.1	40.2	13	35.3	36.9
2	33.2	39.5	14	35.6	36.1
3	33.3	39.1	15	35.9	35

4	33.4	38.6	16	35.9	35
5	33.6	38.5	17	36.1	34.4
6	34	37.8	18	36.2	34.2
7	34.3	37.6	19	36.4	34.1
8	34.6	37.7	20	36.4	34.1
9	34.8	37.7	21	36.5	34
10	35.2	36.7	22	36.5	34
11	35.2	37.1	23	36.6	34
12	35.3	36.9	24	36.7	34

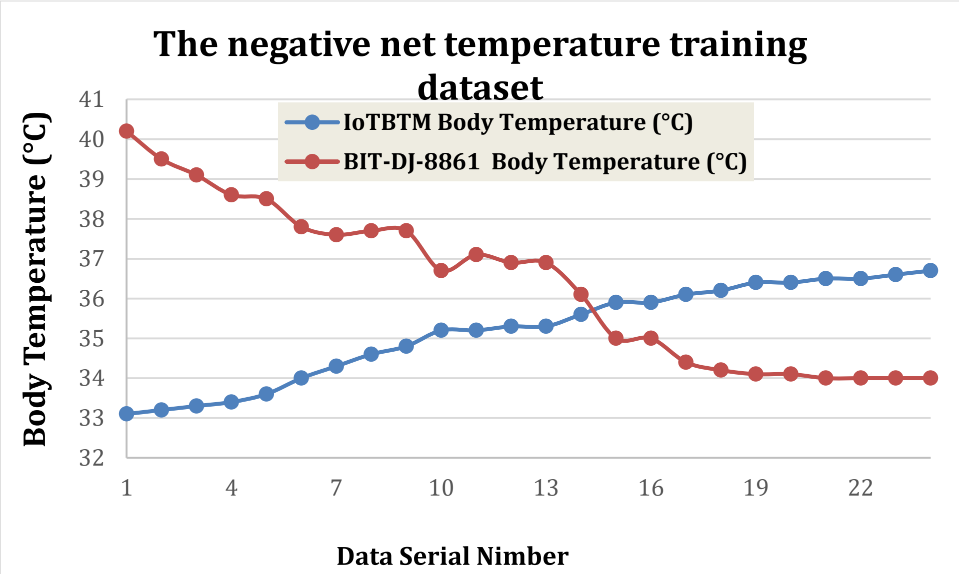

Figure 6: The scatter plot of IoTBTM measured body temperature (°C) and the BIT-DJ- measured body temperature (°C) for the negative net temperature training dataset

The paired-difference t-test with confident level at 95% was conducted for the **negative net temperature training dataset** and the results show that the lower and the upper point are -1.293 and 1.293 respectively with the sample mean of 1.2025 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 7.

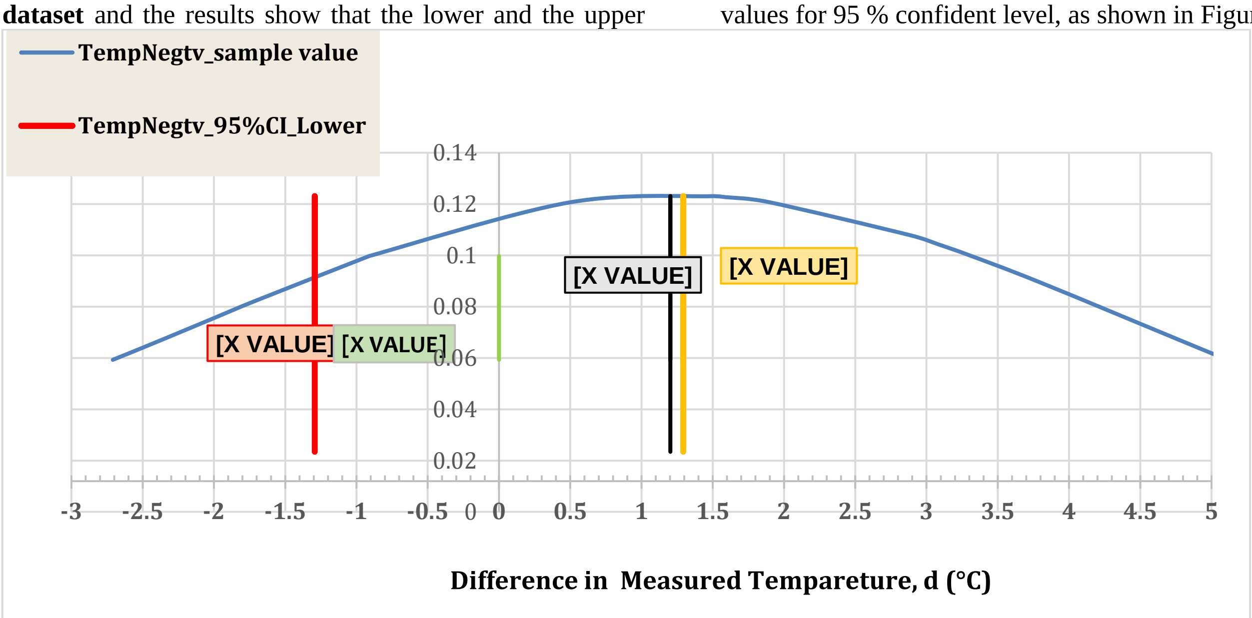

Figure 7: The graph of the paired-difference t-test result for the negative net temperature training dataset

Furthermore, based on the training dataset in Table 3, a regression model was developed in order to minimize the error between the IoTBTM device measured body temperature values and the BIT-DJ-8861 device measured body temperature values. The model in Equation 10 was developed using Microsoft excel solver tool. The model in Equation 10 was used for both negative net temperature training and validation datasets.

$$PDJ8861_k = 0.241(IoTBTM_k)^3 - 2.7145(IoTBTM_k)^2 + 102.63(IoTBTM_k) - 1264.6 \quad (10)$$

Where $PDJ8861_k$ is the kth predicted value of body temperature measurement with BIT-DJ-8861 device and ($IoTBTM_k$ is the kth body temperature measurement with the IoTBTM device.

The analytical model in Equation 10 was used to predict the expected value of body temperature measurement with BIT-DJ-8861 device from any given value of body temperature measurement with the IoTBTM device. The paired-difference t-test with confident level at 95% was conducted for the prediction of the **negative net temperature training dataset** and the results (in Figure 8) show that the lower and the upper point are -0.1546 and 0.1546 respectively with the sample mean of 0.0034 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 8. Also, it can be seen that the training dataset sample mean error before the model was applied was 1.2025 and after the model was applied, the sample mean error had reduced to 0.0034 . This showed that the model effectively minimized the error in the training dataset.

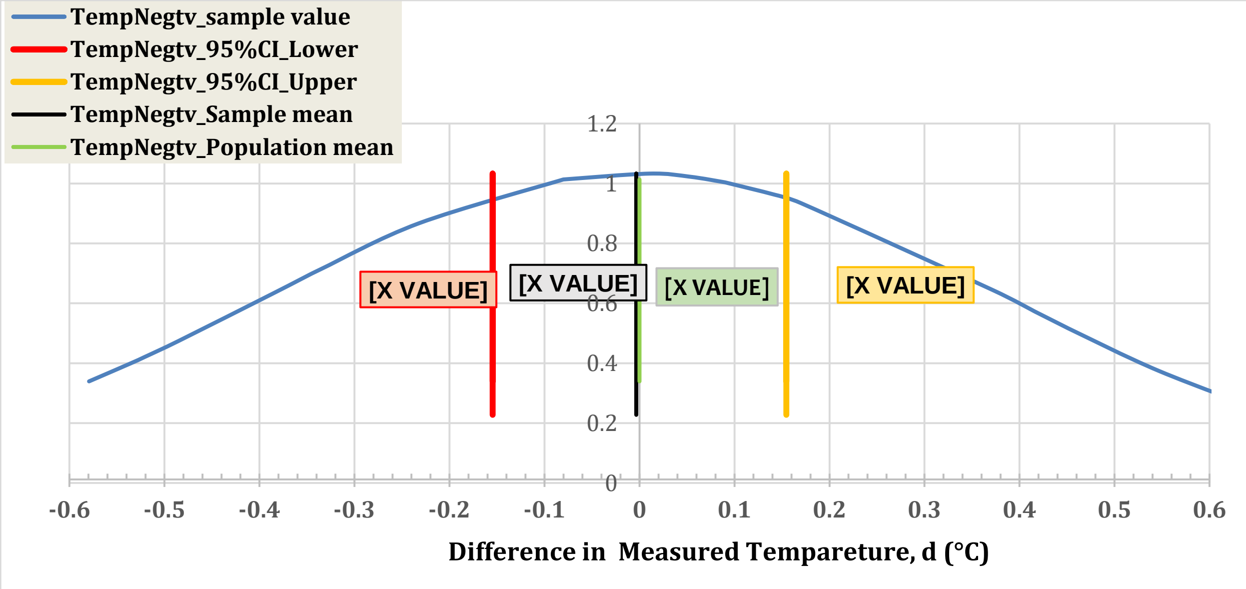

Figure 8: The graph of the paired-difference t-test result for the model optimised negative net temperature training dataset

Similarly, 23% of negative temperature data which represent 19 data records (**Table 4)** was used for cross validation of the optimisation model for the **negative net temperature training dataset**. The paired-difference t-test with confident level at 95% was conducted for the **negative net temperature cross validation dataset without the optimisation model** and the results (in Figure 9) show that the lower and the upper point are -2.0353 and 2.0353 respectively with the sample mean of 1.1428 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 9.

Similarly, the paired-difference t-test with confident level at 95% was conducted for the model predict **negative net temperature cross validation dataset** and the results (in Figure 10) show that the lower and the upper point are -0.2783 and 0.2783 respectively with the sample mean of -0.00208 which falls within the acceptable range of values for 95 % confident level, as shown in Figure 10.

Also, it can be seen that the validation dataset sample mean error before the model was applied was 1.1428 and after the model was applied, the sample mean error had reduced to -0.00208. This showed that the model effectively minimized the error in the validation dataset as well.

Table 4: The negative net temperature validation dataset in degree centigrade

S/N	IoTBTM Body Temperature (°C)	BIT-DJ-8861 Body Temperature (°C)
1	33.5	38.7
2	34.2	38
3	35.1	37.5
4	35.6	36.3
5	35.9	35.3
6	36.1	34.6
7	36.3	34.3

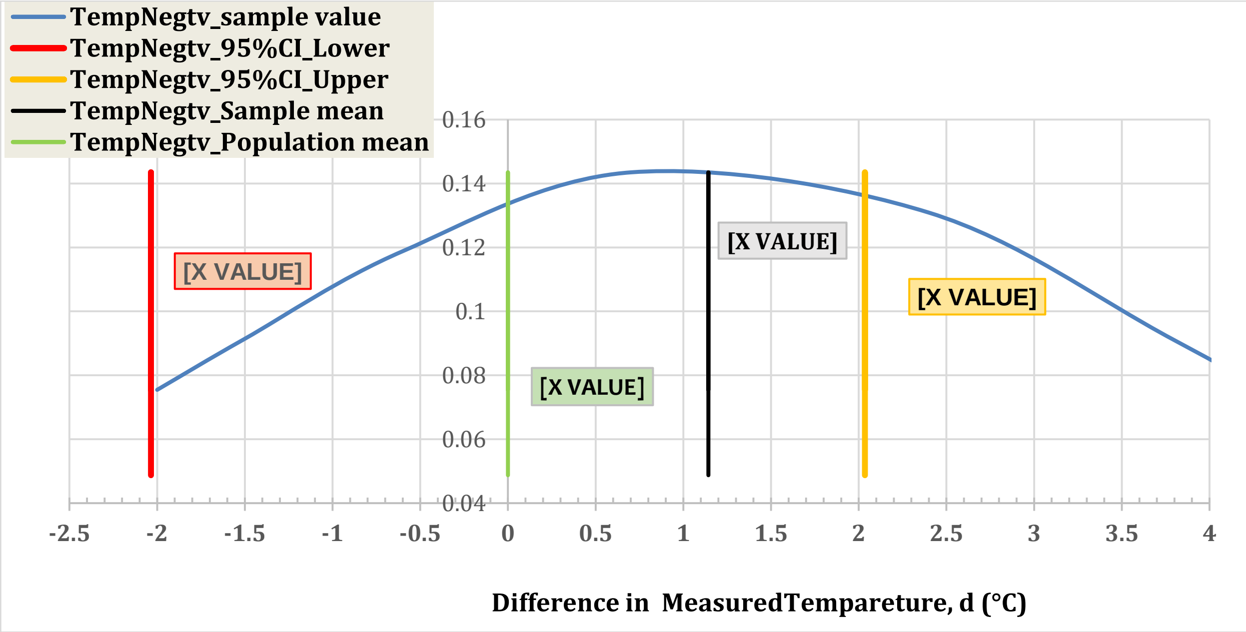

Figure 9: The graph of the paired-difference t-test result for the negative net temperature validation dataset

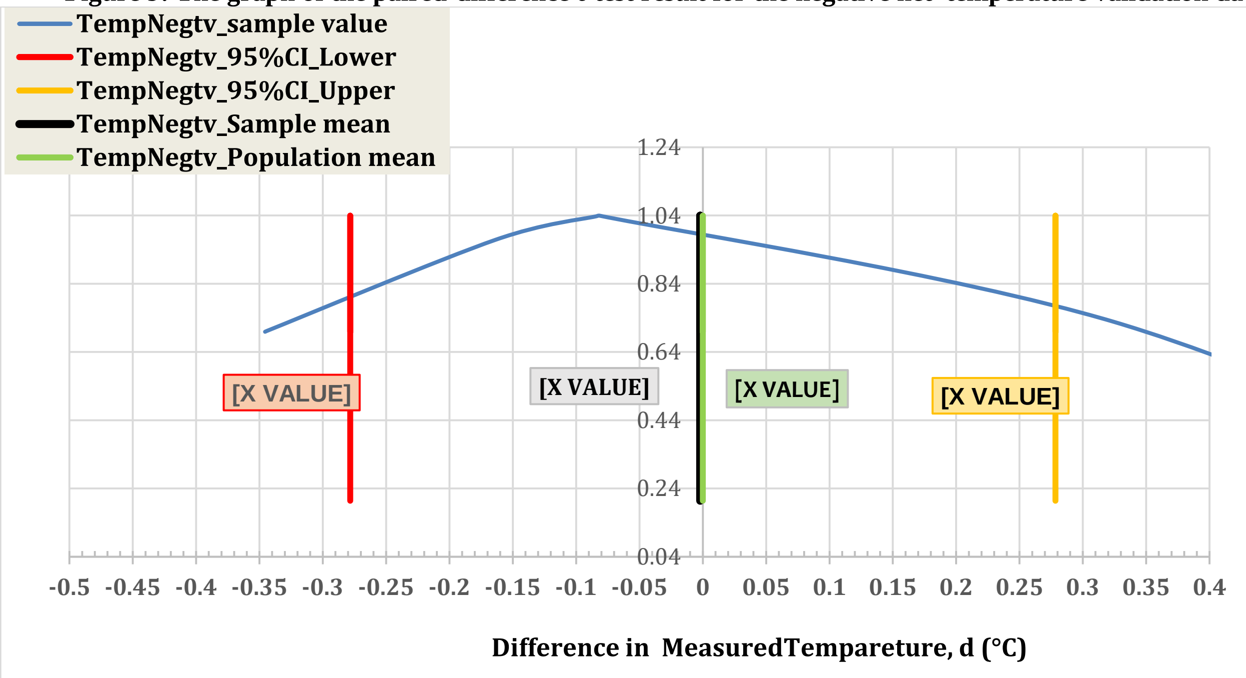

Figure 10: The graph of the paired-difference t-test result for the model optimised negative net temperature validation dataset

5. Conclusion

The evaluation of body temperature measuring device presented. The measurement accuracy of the device was evaluated with respect to the Body Infrared Thermometer DJ-8861 (BIT-DJ-8861) device. The dataset for the study was divided into two categories, the dataset with body temperature values greater than the ambient temperature (which are referred to as the positive net temperature dataset) and the dataset with body temperature values less than the ambient temperature (which are referred to as the negative net temperature dataset).

The positive net temperature dataset was further split into training dataset and validation dataset and optimization model was developed to improve on the measurement accuracy of the evaluated body temperature measuring device. The results of the paired-difference t-test show that the cubic regression model developed was able to minimize the mean error of both the training and validation dataset. Similar tests and results were also obtained for the negative net temperature dataset. Essentially, the ideas presented in this paper can be used to evaluate and enhance the measurement accuracy of body temperature measuring devices with respect to a reference device with already known measurement accuracy.

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