Paired T-Test Evaluation Of Portable Embedded System For Blood Pressure Measurement

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***Abstract*— In this paper, paired t-test evaluation of portable embedded system for blood pressure measurement is presented. Field measure 84 paired datasets used are measured with the portable embedded system for blood pressure measurement (PES4BPM) device and the BP Accoson and Son (Surgical) Ltd 5PQ blood pressure device used in the hospital. In order to develop a model that will aid to minimize the error, the data was further classified into two, namely training data model and cross validation. Specifically, 75% of the dataset were used for training which consist of 63 data records while 25% were used for cross validation, which represent 21 data records. Based on the training dataset, an optimization model was developed to minimize the error between the PES4BPM device measured blood pressure and the BP Accoson and Son (Surgical) Ltd 5PQ blood pressure device measured values. The results show that the blood pressure sample mean are -0.2482 and 0.0518 for the actual training dataset and the optimized model predicted dataset respectively. It can be seen that absolute value of the mean of the difference is 0.0518 with the optimization model whereas without optimization model the mean of the difference is 0.2482 which shows 79.1 % reduction in the absolute value of the mean of the difference in the two datasets. Essentially, the optimization model makes the PES4BPM device measured blood pressure more accurate with respect to the hospital device measured blood pressure.**

Keywords*— Smart Systems Application, Paired T-Test, BP Accoson And Son (Surgical) Ltd 5PQ Blood Pressure Device, Microcontroller-Based Blood Pressure Measuring Device

1. Introduction

The network technologies, namely wired network, wireless network, satellite network and fiber optics network have evolved over the years to give rise to the Internet [1,2,3,4,5,6,7,8, 9,10,11, 12, 13, 14,15,16,17,18,19,20,21,22,23,24,25,26,27]. AT the same time, software technologies haves also evolved into web applications, mobile applications, cloud computing solution, Internet of Things-based software solutions and other software intensive solutions [28,29, 30,31,32,33,34,35,36,37,38,39,40, 41,42,43,44, 45,46,47,48, 49,50,51,52, 53,54,55,56, 57,58, 59]. In addition, the electronic technologies have also evolved and integrated with the software and network technologies and this has brought about microcontroller-based solutions, embedded systems, networked sensor solutions, smart systems and applications as well as internet of things. As such, there are diverse technological solutions to any problem. In this paper, the focus is on embedded system for blood pressure measurement.

Basically, embedded system is a microcontroller-based system (in some cases microprocessor based system) which has been designed with requisite electronic components and firmware targeted for a specific task or application [60,61,62]. Nowadays, most of the embedded systems are equipped with network connectivity to enable remote communication and control of the system [63,64,65]. Importantly, the embedded system concept has evolved to give rise to various forms of sensor nodes, Internet of Things applications, wireless sensor networks, smart systems [66,67,68].

In this paper, the concept of embedded system is employed in a blood pressure measurement device [69,70,71]. The device has blood pressure sensor, the microcontroller unit, other relevant peripherals and wireless internet access facility that enables communication and exchange of data with web application designed specifically for the portable embedded system for blood pressure measurement (PES4BPM) device [72,73].

Specifically, the main focus in this paper is to evaluate the accuracy of the PES4BPM device. For this purpose, paired t-test statistical analysis approach is employed to compare the mean of a paired of blood pressure datasets that were simultaneously captured using the PES4BPM device and also a reference BP Accoson and Son (Surgical) Ltd 5PQ blood pressure measuring device [74,75,76]. The study is to determine if the PES4BPM device blood pressure measurements are as good as that of the reference BP Accoson and Son (Surgical) Ltd 5PQ blood pressure measuring device. In the case where the PES4BPM device is not good enough, then calibration of the PES4BPM device will be required. However, the calibration is not discussed in this paper; rather, it is a noted as issue for further studies.

2 Methodology

2.1 The analytical expression for the paired t-test analysis based on empirically measured blood pressure datasets

Paired t-test is performed using the blood pressure dataset $B_{D,k}$ measured with the portable embedded system for blood pressure measurement (PES4BPM) device and the dataset $B_{H,k}$ measured using the BP Accoson and Son (Surgical) Ltd 5PQ blood pressure device used in the hospital. Each of the two datasets has 84 paired data item denoted as $B_{D,k}$ and $B_{D,k}$. The difference between corresponding $B_{D,k}$ and $B_{D,k}$ is denoted as $D_{SR,k}$ where;

$$D_{SR,k} = B_{H,k} - B_{D,k} \text{ for k = 1,2, 3,…N} \quad 1$$

Let $\bar{D}$ denote the mean of $D_{SR,k}$ where;

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

Let S_D denote the standard deviation where;

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

Let SE_D denote the standard error where;

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

Let t_D denote the t-statistic where;

$$t_D = \frac{\bar{D}}{SE_D} \quad 5$$

The degree of freedom, df is computed as;

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

Let α denote the significance value and $t_{Dcritical}$ denote the critical value where;

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

The confidence interval, $CI_{D\alpha}$ in terms of SE_D and α is expressed as follows;

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

If the mean of $B_{D,k}$ and $B_{D,k}$ are the same or there is no significance difference between the mean of $B_{D,k}$ and $B_{D,k}$ then the value obtained for t_D will be such that;

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

2.2The field measured blood pressure paired datasets

Both the PES4BPM device and the hospital blood pressure measurement device were employed to measure blood pressure in millimeter mercury (mmHg). The total of 84 patient's data was captured in this parameter and shown in Table 1 and Figure 1. Specifically, Table 1 shows the complete paired dataset in millimeter mercury (mmHg); RM for the dataset captured using the PES4BPM device and HM for the dataset captured using the hospital blood pressure measurement device.

Table 1: The complete paired dataset in millimeter mercury(mmHg); RM for the dataset captured using the PES4BPM device and HM for the dataset captured using the hospital blood pressure measurement device

S/N	RM(mmHg)	HM(mmHg)	S/N	RM(mmHg)	HM(mmHg)	S/N	RM(mmHg)	HM(mmHg)
1	88.5	90	29	114.1	113	57	124.8	123.8
2	92	92.3	30	114.1	112.7	58	124.8	124
3	92.7	93.1	31	114.5	113.1	59	125	125.4
4	97.1	95.2	32	114.7	113.2	60	126.3	125.3
5	99.2	98.6	33	116.2	120	61	126.3	125.6
6	99.5	98.7	34	116.2	120	62	126.4	127.9
7	99.7	99.2	35	117.2	118.4	63	126.4	128
8	99.8	99.9	36	118.2	117.2	64	128.2	130
9	99.9	98.8	37	118.4	120	65	129.1	130
10	100.1	98.9	38	118.9	120	66	129.2	128.5
11	100.1	98.8	39	119.4	123.1	67	129.5	128.9
12	105.1	106.2	40	120.1	121.5	68	130.8	129.8
13	105.8	105.8	41	120.2	119.2	69	130.9	130.1
14	106	107.6	42	120.2	120	70	131	130.7
15	106.2	107.8	43	120.2	119.4	71	131.4	130.1

16	106.5	108	44	120.4	120.2	72	131.6	130.5
17	108	106.2	45	120.7	120.5	73	133.1	131.8
18	108.1	107.8	46	120.9	121	74	133.7	132.8
19	108.2	109.2	47	120.9	120.6	75	133.9	132.8
20	108.2	108.2	48	121.2	121.1	76	134.1	132.7
21	108.2	110	49	121.5	119.9	77	134.1	133
22	109.7	110	50	121.9	120.2	78	135.1	133.2
23	110.6	112.1	51	122.2	120	79	138.2	138
24	110.9	110	52	123.2	121.8	80	138.6	138.5
25	111.2	111.4	53	123.7	122.5	81	138.9	137.7
26	111.2	111.1	54	124.4	122.2	82	139.5	138.3
27	112.1	110	55	124.7	123.7	83	140.4	140
28	112.3	110	56	124.7	123.2	84	140.8	139.6

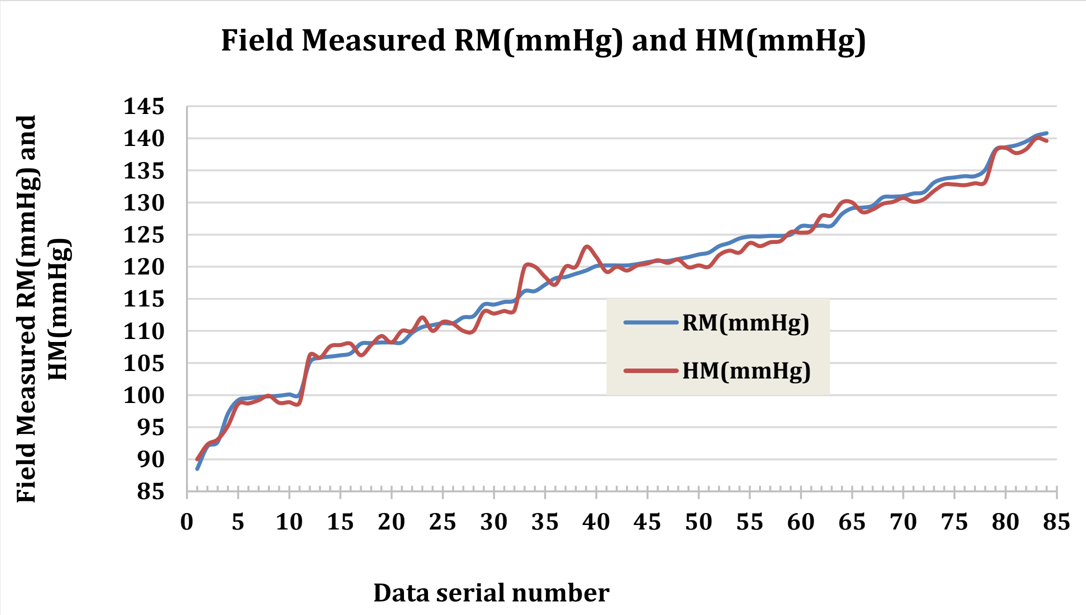

Figure 1 The RM for the dataset captured using the PES4BPM device and HM for the dataset captured using the hospital blood pressure measurement device

In order to develop a model that will aid to minimize the error, the data was further classified into two, namely training data model and cross validation. 75% were used for training data which they represent 63 patient's data (shown in Table 2 and Figure 2) while 25% were used for cross validation, which represent 21 patient's data (shown in Table 3 and Figure 3)

Table 2 The training dataset extracted from RM, the dataset captured using the PES4BPM device and HM, the dataset captured using the hospital blood pressure measurement device

S/N	RM(bpm)	HM(bpm)	S/N	RM(bpm)	HM(bpm)	S/N	RM(bpm)	HM(bpm)
1	88.5	**90**	19	112.3	110	38	124.7	123.2
2	92	92.3	20	114.1	113	39	124.8	124
3	97.1	95.2	21	114.5	113.1	40	125	125.4
4	99.2	98.6	22	114.7	113.2	41	126.3	125.6
5	99.7	99.2	23	116.2	120	42	126.4	127.9
6	99.8	99.9	24	117.2	118.4	43	128.2	130
7	100.1	98.9	25	118.4	120	44	129.1	130

8	100.1	98.8	26	118.9	120	45	129.5	128.9
9	105.8	105.8	27	120.1	121.5	46	130.8	129.8
10	106	107.6	28	120.2	119.2	47	131	130.7
11	106.5	108	29	120.2	119.4	48	131.4	130.1
12	108	106.2	30	120.4	120.2	49	133.1	131.8
13	108.2	109.2	31	120.9	121	50	133.7	132.8
14	108.2	108.2	32	120.9	120.6	51	134.1	132.7
15	109.7	110	33	121.5	119.9	52	134.1	133
16	110.6	112.1	34	121.9	120.2	53	138.2	138
17	111.2	111.4	35	123.2	121.8	54	138.6	138.5
18	111.2	111.1	36	123.7	122.5	55	139.5	138.3
19	112.3	110	37	124.7	123.7	56	140.4	140

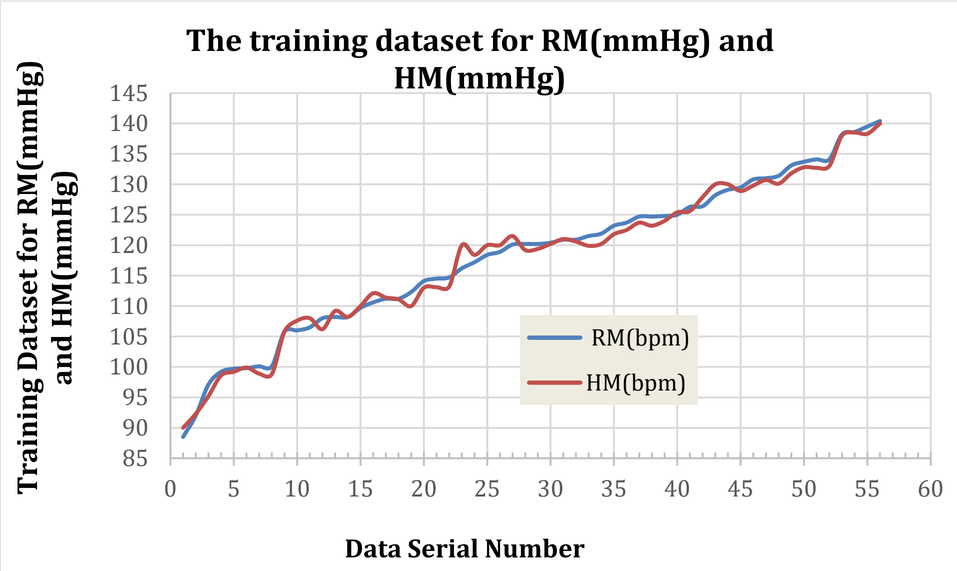

Figure 2 The training dataset extracted from RM, the dataset captured using the PES4BPM device and HM, the dataset captured using the hospital blood pressure measurement device

Table.3: The validation dataset extracted from RM, the dataset captured using the PES4BPM device and HM, the dataset captured using the hospital blood pressure measurement device

S/N	RM(bpm)	HM(bpm)	S/N	RM(bpm)	HM(bpm)	S/N	RM(bpm)	HM(bpm)
1	92.7	93.1	10	114.1	112.7	19	124.8	123.8
2	99.5	98.7	11	116.2	120	20	126.3	125.3
3	99.9	98.8	12	118.2	117.2	21	126.4	128
4	105.1	106.2	13	119.4	123.1	22	129.2	128.5
5	106.2	107.8	14	120.2	120	23	130.9	130.1
6	108.1	107.8	15	120.7	120.5	24	131.6	130.5
7	108.2	110	16	121.2	121.1	25	133.9	132.8
8	110.9	110	17	122.2	120	26	135.1	133.2
9	112.1	110	18	124.4	122.2	27	138.9	137.7
10	114.1	112.7	19	124.8	123.8	28	140.8	139.6

3. Results and discussion

The results of the analysis of the field data using paired t-test method at 95 percentages confident level is shown in Figure 4. From the training data above, the model was developed in order to minimize the error or any out flyer data obtained during the measurements. This model was generated using Microsoft excel with the trend line equation (Figure 5). The model was further modifying with the used of solver in order to have a good predicted value for the hospital measurement device. The model is very significant because it will enhance the research device with low sensitive sensors to measure close value as high sensitive sensors. The model employed is in equation 10.

$$HM = \mathbf{97.556}\, exp^{(0.0066RM)} \quad (10)$$

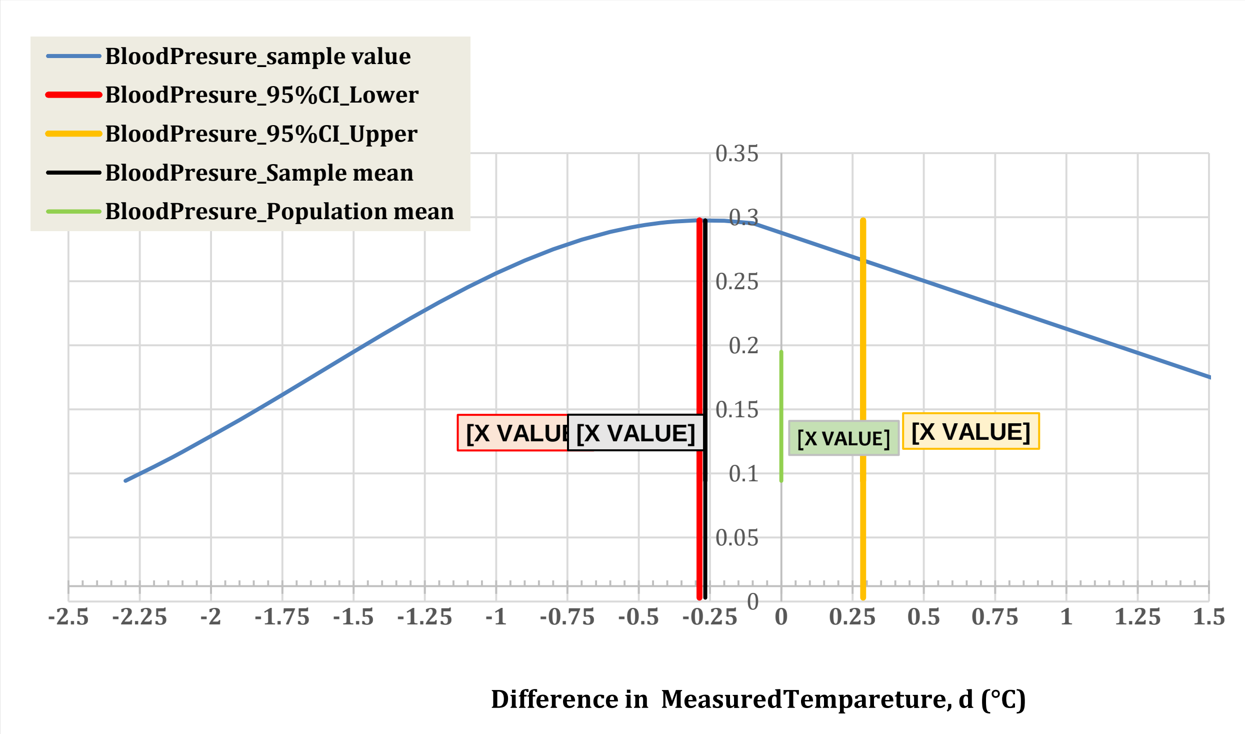

Figure 4: The graph showing the paired t-test of blood pressure using the actual measured dataset

After the blood pressure measurement modelling or calibration was done using the training dataset which in turn aid to predict a new value for the system optimization, it was observed that the error has been minimize (Figure 6). Applying paired t-test shows that the blood pressure value at 95 percentages confident level has lower point and upper point at -0.2863 and 0.28625 while the sample mean is 0.0457 which is smaller than the absolute value of the error -0.2667 obtained without the optimization of the measured blood pressure dataset. Comparatively, the paired t- test results shows that there is no significant different between the hospital device with the research device after applying the model developed to optimize the system.

Similarly, Figure 7 and Figure 8 indicated the paired t-test of blood pressure for the actual training blood pressure dataset and the optimized model predicted training data. The results show that the blood pressure sample mean are -0.2482 and 0.0518 for the actual training dataset and the optimized model predicted dataset respectively. It can be seen that absolute value of the mean of the difference is 0.0518 with the optimization model whereas without optimization model the mean of the difference is 0.2482 which shows 79.1 % reduction in the absolute value of the mean of the difference in the two datasets. Essentially, the optimization model makes the PES4BPM device measured blood pressure more accurate with respect to the hospital device measured blood pressure.

Similarly, Figure 9 and Figure 10 indicated the paired t-test of blood pressure for the actual validation blood pressure dataset and the optimized model predicted validation data. The results show that mean of blood pressure sample mean are 0.30336 and -0.0036 for the actual validation dataset and the optimized model predicted dataset respectively.

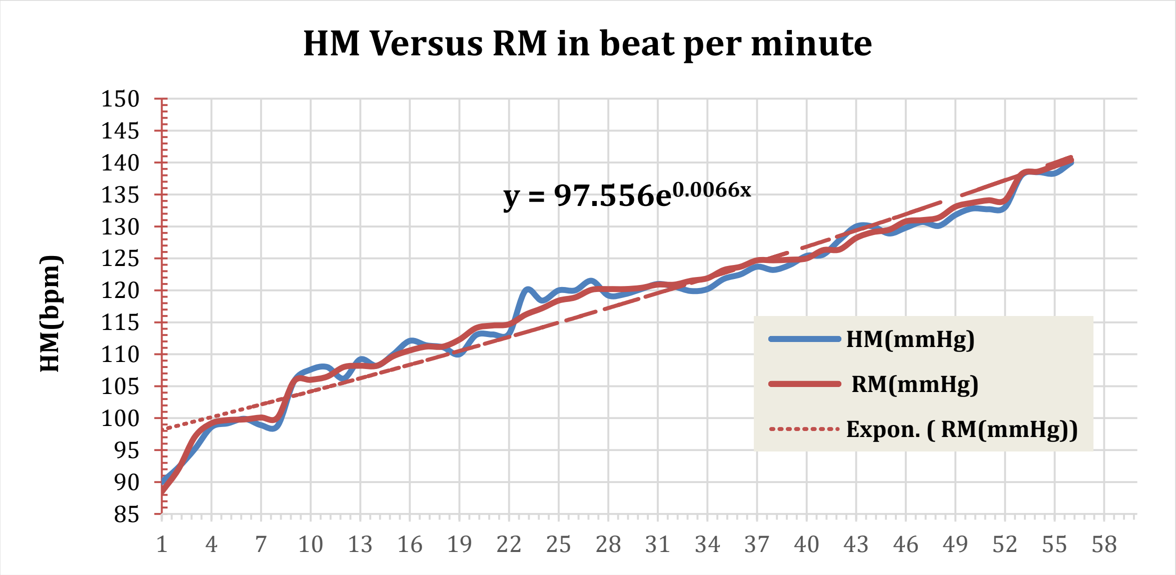

Figure 5: The graph shows the plot of HM versus RM for blood pressure model.

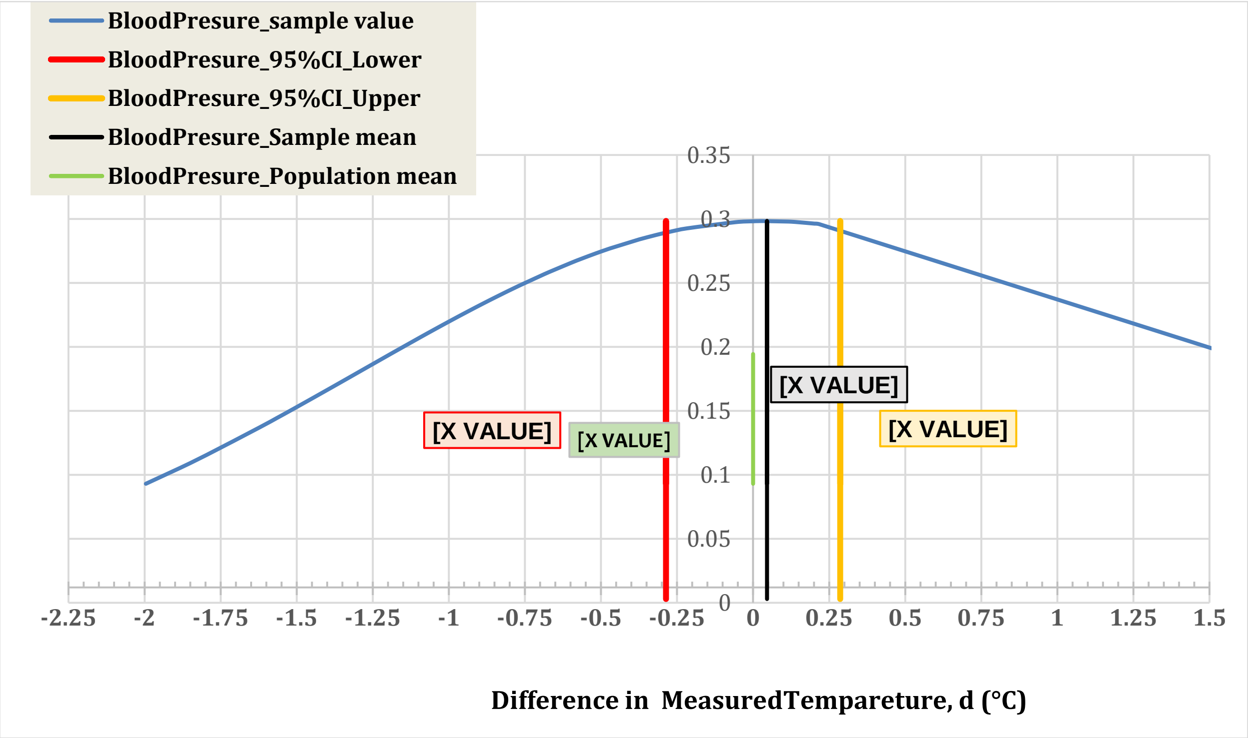

Figure 6: The graph shows the paired t-test of complete predicted data for blood pressure

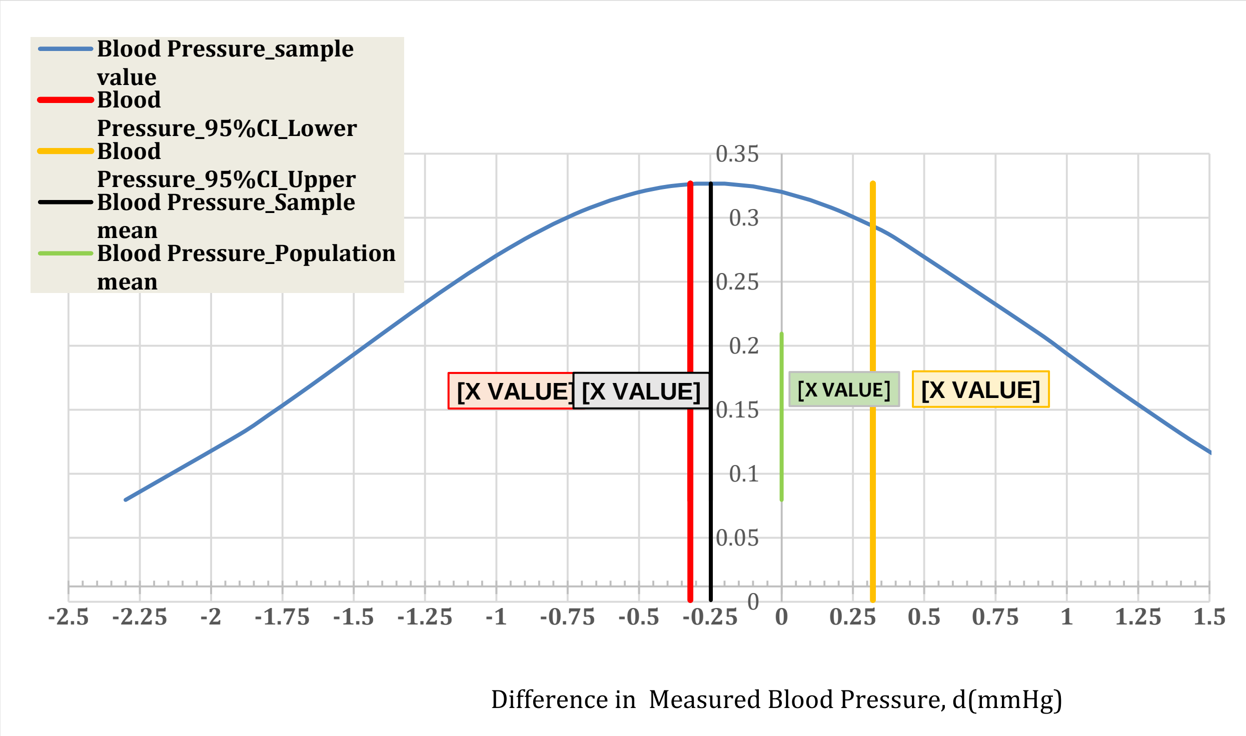

Figure 7: The graph shows the paired t-test using the actual training blood pressure dataset

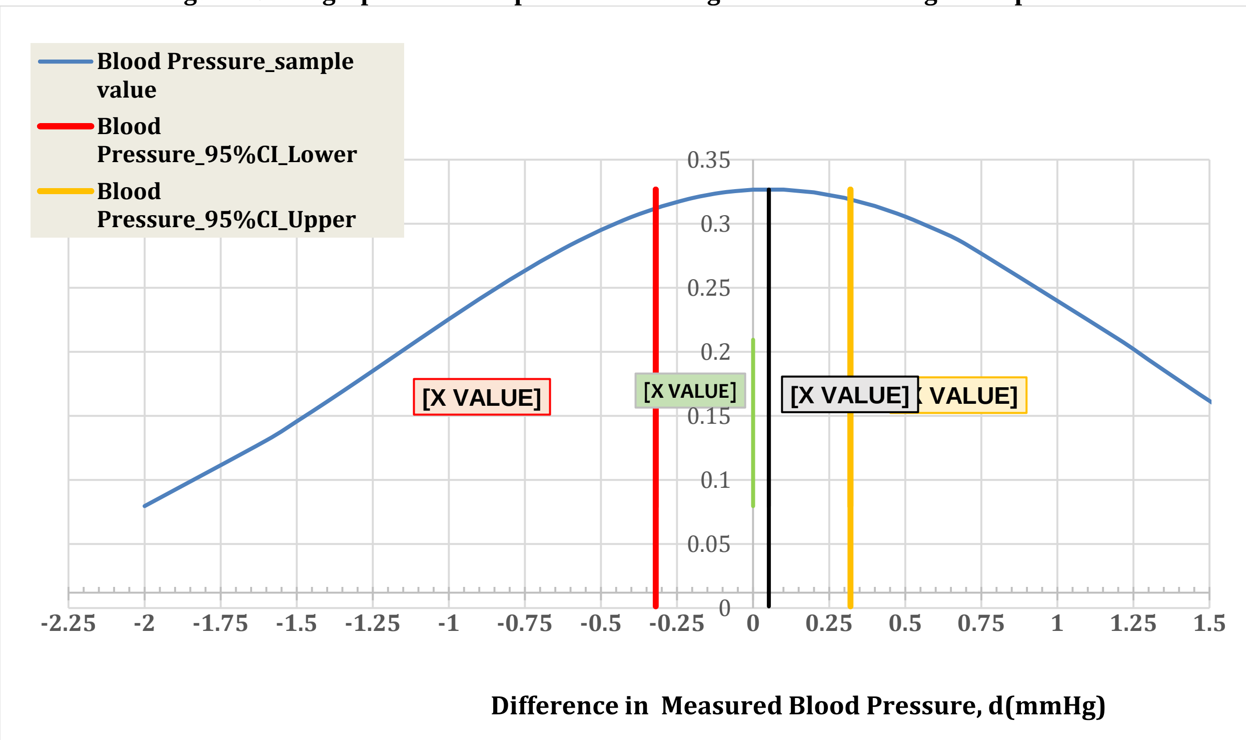

Figure 8: The graph shows paired t-test of blood pressure based on the optimized model predicted training dataset

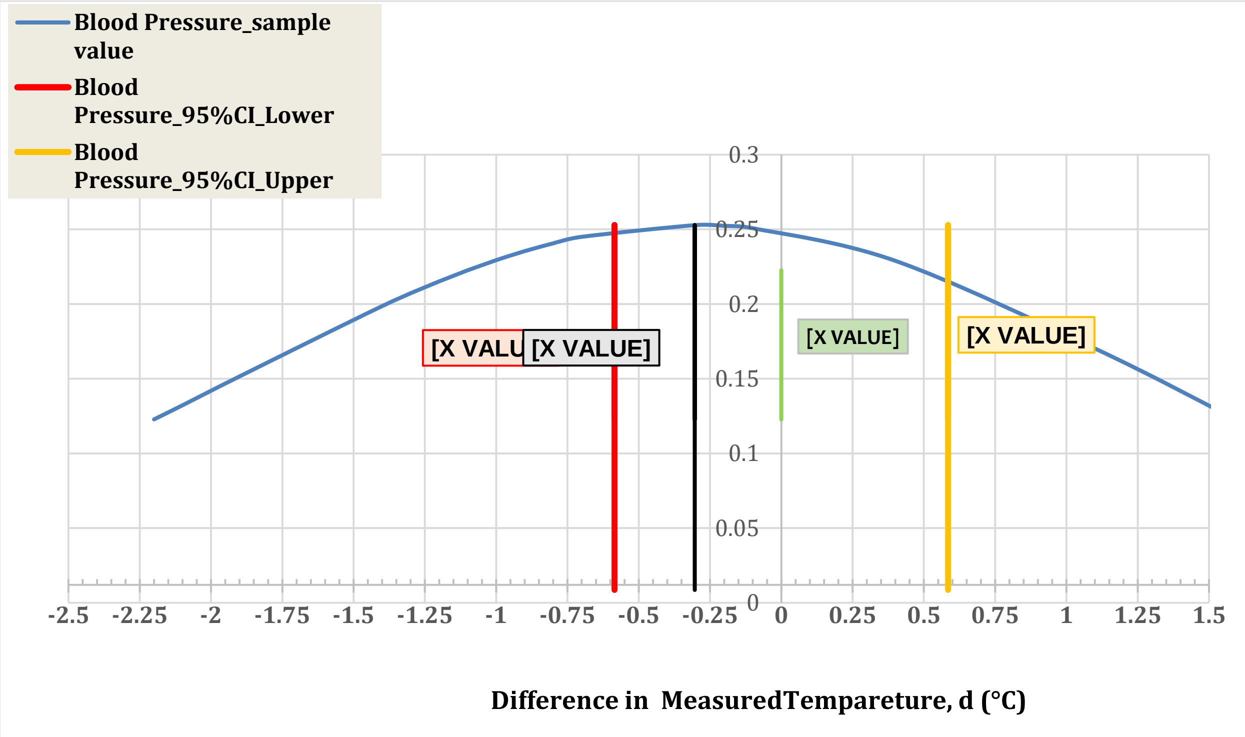

Figure 9: The graph shows paired t-test of blood pressure (actual) for validation

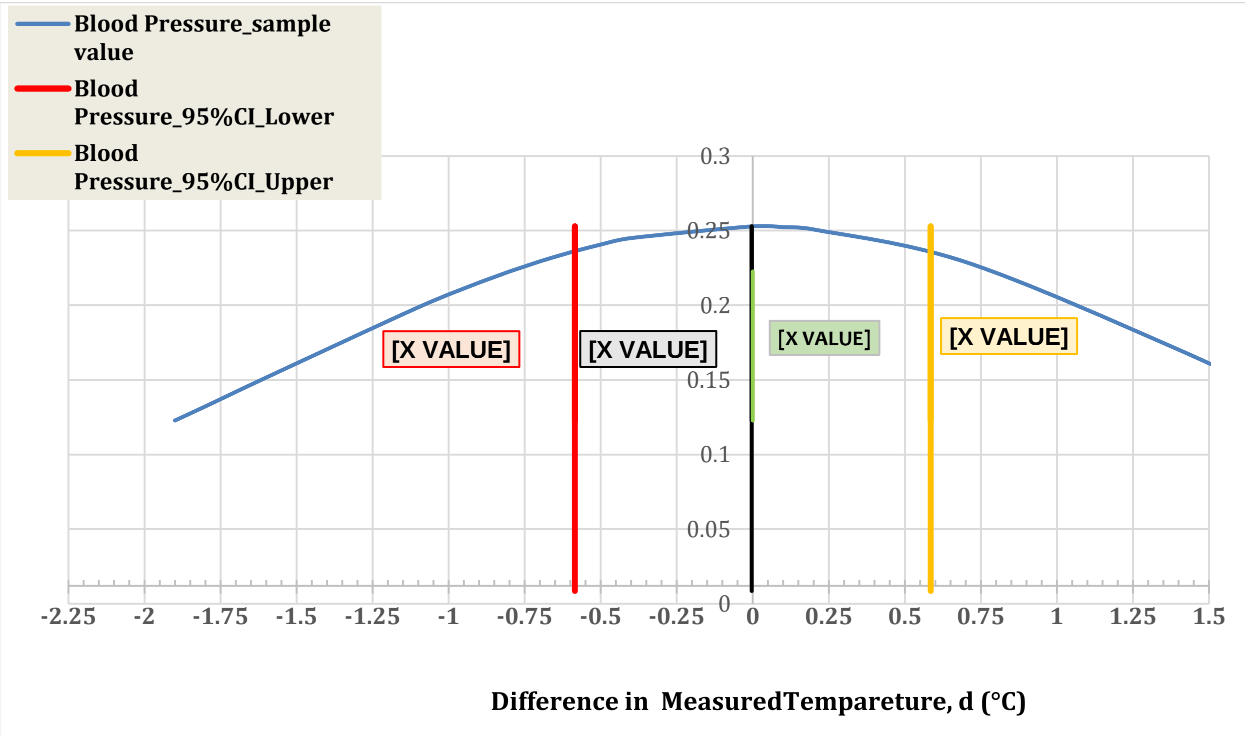

Figure 10: The graph shows paired t-test of blood pressure based on the optimized model predicted validation dataset

4. Conclusion

The measurement accuracy of a portable embedded system for blood pressure measurement (PES4BPM) device with respect to blood pressure measured using the BP Accoson and Son (Surgical) Ltd 5PQ blood pressure device used in a case study hospital is presented. The paired t-test approach is used for the analysis. The dataset was divided into training and validation datasets and then an optimization model was developed for improving the accuracy of the PES4BPM device measured blood pressure with respect to the BP Accoson and Son (Surgical) Ltd 5PQ device measured blood pressure. The results showed that the optimization model was able to improve the absolute value of the mean of the difference in the two datasets by up to 79 %.

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