Characterization of Temperature Sensors for Human Body Temperature

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Introduction

Body Temperature is an extremely useful metric in measure heat generation and dissipation. This gives us insights into secondary parameters like sweating, metabolic rate, thermo-equilibrium and activity. Moreover, further diagnostic information can be gleaned from temperature differences between various sites on the body, with one of the most important metrics being body core temperature.

Hence, there have been a variety of approaches in measurement of body temperature in general, and estimation of core body temperature in particular. One of the earliest attempts that gained prominence was the water thermoscope, developed by Galileo Galilei in the 17th century.

Current Techniques

Current approaches at body temperature measurement include digital thermometers, mercury and alcohol thermometers, thermocouples, optical temperature sensors and MEMS temperature sensors.

Usual sites for body temperature measurement are

1. underarm
2. mouth
3. rectum
4. ear
5. forehead

However, it has been shown that temperature readings at the chest are more strongly correlated to core body temperature that most of these sites.

We have integrated a temperature sensor into our remote patient monitoring device, QuasaR™, which measures and reports the body temperature at the chest (Figure 3) and reports estimated core body temperature based on these readings. The QuasaR™ devices uses a MEMS sensor MAX30205, coupled to a thermal slug in contact with the skin.

Water bath based temperature sensor characterization

Setup

We measured the accuracy and reliability of the temperature sensor in our QuasaR™ device, by immersing the device in a temperature-controlled water bath. After keeping the device immersed for 10 minutes to account for any discrepancies in heat transfer, we recorded temperature readings for 30 seconds, using 3 temperature sensors (clinical thermometer, thermocouple, QuasaR™).

The setup is laid out in Figure 1. We took 1 reading for the water heater, clinical thermometer, thermocouple in each trial, and 1667 temperature readings in QuasaR™ over 30s at 27fps for each trial. We ran a total of 35 trials at 5 temperatures (7 readings at each temperature).

Results

We saw minimal variation between multiple trials at the same temperature for the same device.

QuasaR aligned more closely with the clinical thermometer than the thermocouple. The results are discussed in Table 1, Figure 2.

Table 1. Comparison of water bath temperature

Device	QuasaR™	Thermocouple
Maximum Error	0.5 °C	0.6°C
Minimum Error	0 °C	0.4 °C
Average Error	-0.2 °C	-0.52 °C

Figure 1. Water bath based experimental setup

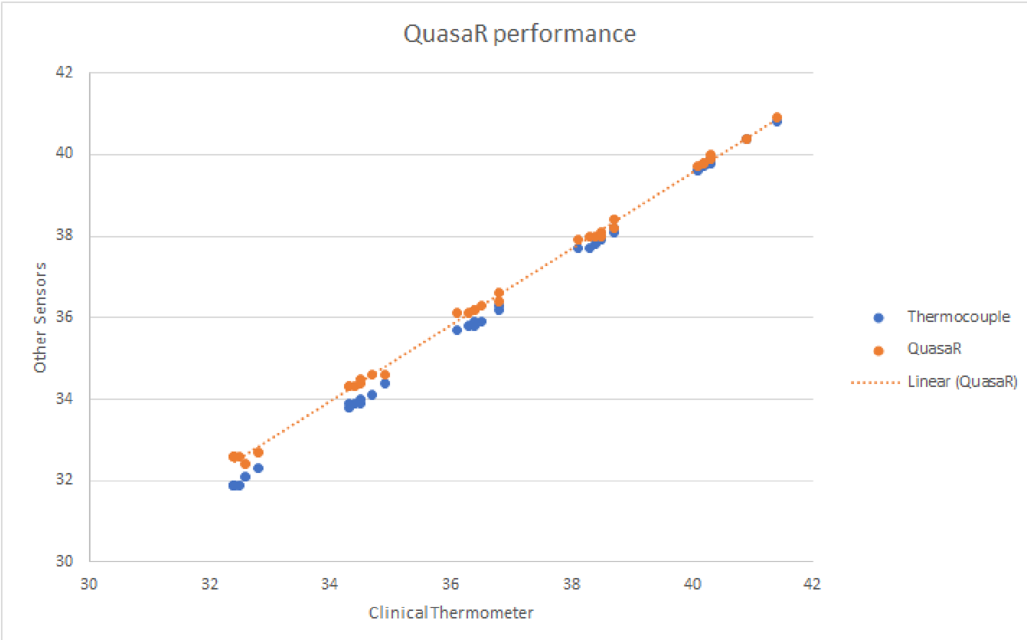

Figure 2. Comparison of accuracy

Body Temperature characterization

Given the superior performance of QuasaR™ in the water bath, we now measure the body temperature at the chest using QuasaR™.

We ran 4 trials, where we attached the QuasaR™ device at the chest using a strap (see Figure 3), and measured the body temperature, averaged over 30s. We use the clinical thermometer to measure underarm temperature for comparison. We wore the device for 10 minutes, followed by 1 30s reading every minute. The results are tabulated in Table 2.

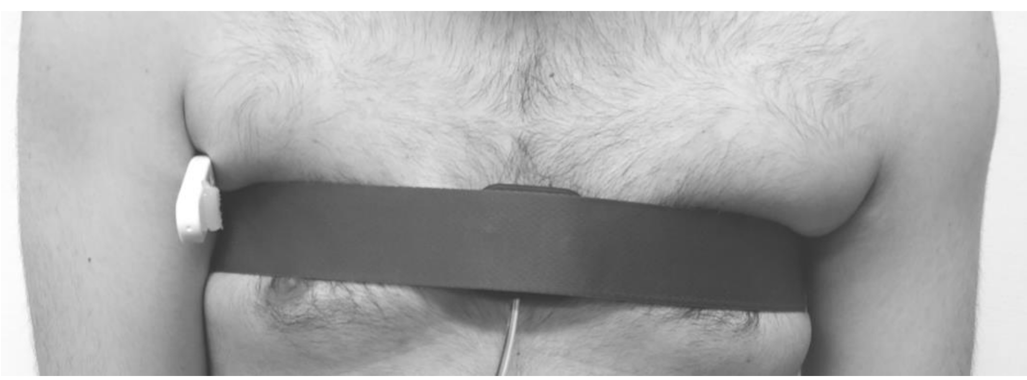

Figure 3. Setup for body temperature comparison using clinical thermometer and QuasaR™

We can see that the temperature readings are largely similar for the QuasaR™ device and the clinical thermometer, with a slight difference in temperature, given that the measurement sites are different. We also see that with time, the temperature reading from QuasaR™ and the clinical thermometer further converge due to the thermal slug, and by extension the temperature sensor in the QuasaR™ device approaching thermal equilibrium with the body.

Table 2. Comparison of Body Temperature

	Trial 1			Trial 2			Trial 3			Trial 4		
Timestamp	Clinical	QuasaR	Diff	Clinical	QuasaR	Diff	Clinical	QuasaR	Diff	Clinical	QuasaR	Diff
t	36.4	39.1	-2.7	36.8	38.1	-1.3	36.2	34.5	1.7	35.7	35.6	0.1
t+1	36.5	38.6	-2.1	37	38.2	-1.2	36.3	34.8	1.5	36.2	35.5	0.7
t+2	36.1	37.6	-1.5	36.8	38.2	-1.4	36.5	35.1	1.4	35.6	35.4	0.2
t+3	36.3	37.7	-1.4	37.1	38.3	-1.2	36.4	35.2	1.2	36.4	35.4	1
t+4	36.2	37.8	-1.6	36.9	38.3	-1.4	36.3	35.4	0.9	36	35.4	0.6

Conclusion

In these trials, we see that the temperature sensor in the QuasaR™ device is extremely accurate. The temperature reading in the water bath experiments are practically identical to that of a clinical thermometer, while the minor but consistent different of around 1°C of the body temperature readings are consistent with current literature for different body sites (chest and underarm).

We can see that the temperature reported by the QuasaR™ device converges and stabilizes in 10-15 minutes Performance can therefore be improved by increasing contact area and decreasing volume of the thermal slug, as that would increase rate of heat transfer and speed up temperature equilibrium between the body surface and the MEMS sensor.

References

1. Crean, Carol, C. Mcgeouge, and Richard O'kennedy. "Wearable biosensors for medical applications." Biosensors for Medical Applications. Woodhead publishing, 2012. 301-330.
2. "Body Temperature." Body Temperature | Michigan Medicine, University of Michigan, 23 Sept. 2018, www.uofmhealth.org/health-library/hw198785.
3. Togawa, Tatsuo. "Body temperature measurement." Clinical physics and physiological measurement 6.2 (1985): 83.