

# Comparative Analysis of Temperature Measurement Methods based on Degree of Agreement

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## Abstract

Many sports have a high risk of climatic ailments, such as hypothermia, hyperthermia, and heatstroke. The measurement of a sportsperson's body core temperature ( $T_c$ ) may have an impact on their performances and it assists them to avoid injuries as well. To avoid complications like electrolyte imbalances or infections, it's essential to precisely measure the core body temperature during targeted temperature control when spontaneous circulation has returned. Previous approaches on the other hand, are intrusive and difficult to use. The usual technique, an oesophageal thermometer, was compared to a disposable non-invasive temperature sensor that used the heat flux methodology. This research indicates that, non-invasive disposable sensors used to measure core body temperature are very reliable when used for targeted temperature control after overcoming a cardiac arrest successfully. The non-invasive method of temperature measurement has somewhat greater accuracy than the invasive approach. The results of this study must be confirmed by more clinical research with various sensor types to figure out if the bounds of agreement could be increased. This will ensure that the findings are accurate based on core temperature.



**Keywords:** Invasive method, temperature measurement technique, thermal metrology, thermal variation modeling, core temperature

## 1. Introduction

Temperature is a widely used specification, and as a result, a clear traceability trail has been built. Over the last many years, evaluations of several industrial core temperature measurements have been carried out. To better define three-dimensional temperature field and evaluate thermal descriptors of prognostic value, there has been a push to collect more temperature data during treatment. One or two fixed sites of temperature measurement are no longer deemed suitable for research purposes. Catheters and heat mapping methods should be utilized in conjunction with traditional catheter placement tactics, rather than alone [1-5].



**Figure 1.** Invasive and non-Invasive instrument for temperature measurement

The patient's temperature is monitored and controlled using the non-invasive temperature management system. It utilises reusable pads placed over the patient's chest and thighs to circulate

heated water [6]. As a result, the patient and water, experience a heat exchange. Figure 1 shows invasive and non-invasive instrument for temperature measurement.

Many pieces of tools, particularly in the assembly process, are not intended to be repurposed. Depending on the product's specification, the thermal variance may have a big influence [7-10]. It is necessary to measure the dimensions of the tooling, but doing so on a regular basis is time demanding. An online temperature measuring system might be used in conjunction with thermal variation models to analyze the impact of the system and make adjustments as needed. Tools and equipments, stay in the production, making permanent temperature sensors an easier implementation.

Measuring dimensions becomes more important for producing quality items as technology advances and production specifications tighten. Most of the measurement uncertainty may be attributed to thermal factors, regardless of the dimensional scale. In order to estimate the likely impacts of thermal fluctuation, measurements must be tracked and modelled regularly [11, 12].

### ***Motivation***

The creation of thermal variation models is the fundamental incentive for investigating acceptable temperature measuring systems. To examine how heat variance affects product and equipment integrity, a manufacturer might use such models. Finite Element Analysis and physical data may be used to construct thermal variation models using simulation software, and the results can be fed into further studies such as tolerance analysis.

## **2. Organization of the Research**

The rest of the research study article is organized as follows: Section 3 discusses current research on thermal variation modeling using a variety of methodologies. Section 4 examines the

different strategies for invasively measuring temperature. Section 5 discusses performance metrics of various approaches. The last part discusses the limits of the study.

### 3. Preliminaries

Thermal variation has been described with a particular emphasis on temperature measuring processes such as thermal chip-formation demonstrating for stable stand [13] and the estimate of stable stand features in many traditional approaches. Machine learning methods and finite element analysis have recently been used to estimate thermo mechanical stresses during turning procedures [14]. Mechanical assemblies have also had their thermal variation examined, having effects of temperature on tolerances [15]. To determine the 'working channel' of a gathering process, researchers recently used tolerance analysis to take temperature into account [16].

When power, open circuit, or contact problems occur, thermocouples' self-validation was used to identify odd sensor values [17]. After that, the smart sensor gives the best approximation of the reading. Internal memory and software allow the characterization of individual sensors, as well as improved performance and problem detection [18].

The stability of several kinds of thermocouples have been assessed and compared [19]. Comparisons have also been performed between the sensitivity and the stability of thermocouples constructed from base metals and noble metals. Alloyed thermocouples have a higher degree of homogeneity than pure element thermocouples do [20].

This study takes a look at a variety of current techniques used for measuring core temperature ( $T_c$ ) to emphasize the need for having a single, non-invasive, widely applicable device for doing so. A gadget like this is critical for keeping athletes safe from weather-related ailments while competing, and it may also improve their performance [21].

## **4. Methodologies**

### **4.1 Invasive methods**

#### **4.1.1 Thermocouple measurement**

As seen from the volume of literature on the topic, thermocouples are used to measure the inner machine temperature in an industry. Because of the widely agreed standards for usage, the relative precision of the sensors across a wide measurement range, and their inexpensive cost, these sensors have become more widespread. The suggested process is shown in figure 2. The setpoint has been manually adjusted in order to provide a feedback controller that is composed of an error and an amplifier.

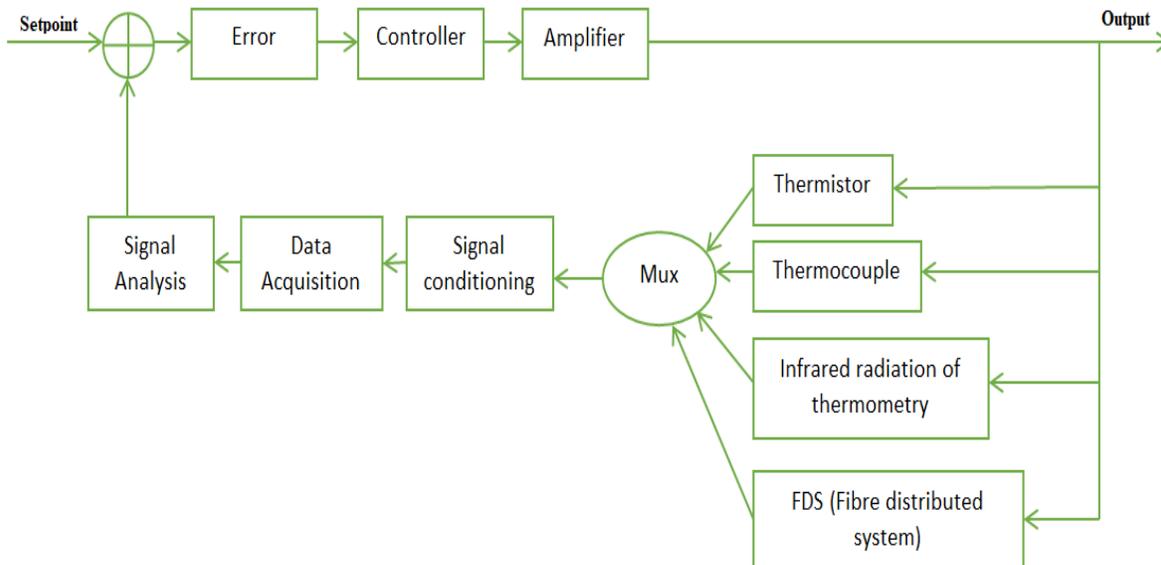
Surface temperature measurements with an electrochemically etched microtip have improved spatial resolution over ordinary soldered Type K thermocouples [22]. The heat created by friction between moving surfaces has been measured using thin-film thermocouples placed on the surface. The research found that with Type K thermocouples, a neural network technique might be used to solve the problem.

#### **4.1.2 Thermometers based on platinum resistance for industrial use**

Resistance-based temperature sensors, such as Industrial Platinum Resistance Thermometers (IPRTs) are available. A platinum wire with a known resistance was used to monitor the temperature with great precision and less current. The resistance of the wire changes depending on the sensor's temperature, and this resistance is converted and compared with a standard resistance material. The platinum material is utilized because of the material's long-term stability and the linear connection between resistance and temperature [23]. The feedback controller embedded inside the sensors' output provides the mux control, which is responsible for

controlling the selection of sensors in the system. This circuit accomplishes the role of maximizing the signal up to the point when it is connected to the mains.

The IPRT type community thermometers are the tougher siblings of the thermometers based on Standard Platinum Resistance Thermometers (SPRTs) used to determine the non-variable points of temperature level. An IPRT adaption for measuring gas turbine stagnation temperature was published in 2013 for high accuracy. Accurate and semi-automatic calibration methods have been devised for site usage, resulting in the decreased drifted slow temperature and shortened standardization periods [24]. Miniature fixed-point cells have been used to investigate the idea of self-testing IPRT sensors for increased long-term stability, so that the sensor does not need to be removed for calibration. In the data collection unit, the results of the signal conditioning circuit are included. The signal analysis unit reduces the amount of error that is passed on to the actual controller unit during the control process.



**Figure 2.** Proposed work flow for experimental setup

#### **4.1.3 Thermistors based on Negative Temperature Co-efficients (NTCs)**

The thermocouples are constructed from various silicon materials and have a non-linear temperature-resistance relationship, with critical calibration. It is possible to achieve a greater degree of sensitivity using semiconductor materials, but frequent calibration is required to prevent sensor drift from having an impact [25].

The voltage has been divided into various levels by voltage divider device that is used to solve temperatures measurement instead of a bridge resistance circuit. This may be difficult if dealing with non-linearity. The thermistor's inherent sensitivity has been used to create a high-resolution thermometer by measuring the voltage divider's resistance.

#### **4.1.4 Temperature sensor by fibre optic distributed system**

Fibre-optic Distributed temperature Sensing systems (FDS) use the changing refractive index of an optical fiber at various temperatures and the resulting influence on collimated monochromatic light that travels along its route. Besides pipeline monitoring for the oil and gas industries, FDS is used to monitor electricity lines up to 30 kilometers long [26].

When using fully dispersed systems, measurements are made along with the fiber at defined spatial intervals. It's possible to have a fully distributed system that uses all three of these techniques. Rayleigh backscatter has been used in Raman-based systems to adjust background effects, but the results have been mixed. In the Light Controlled Factory, this is less of an issue due to the hostile surrounding and distances more than 2 km pose a greater risk.

### **4.2 Non-Invasive Temperature Measurement**

It is possible to classify non-invasive temperature measuring devices under the heading "non- touchable thermal contact with measurement."

### 4.3 Thermometry by infrared radiation

The heat energy emitted from measuring's apparent is measured using electromagnetic energy thermometer sensing element. The amount of energy emitted from a surface varies with its emissivity. The quantity of absorbed and reflected radiation from a surface is expressed as a dimensionless ratio called emissivity. This method of measurement has a high level of uncertainty because of many factors. However, the emissivity may be controlled to some degree by applying an even coating of a known emissivity. The sensors connected with single point, straight scanner through line object, and thermal based imaging camera are the three most common types of commercially available equipment. Observing the temperature may affect the emissivity of a surface since the temperature is an emissivity variable. To account for emissivity fluctuations, a device that measures both emissivity and temperature concurrently has shown promising results.

Non-invasive measurements of high-temperature processes benefit greatly from infrared temperature measurement. By combining infrared (IR) with thermocouples (TC), the better prediction is feasible through heat processing of welding procedure [27]. This method has also been used to detect temperature distributions during titanium-machining chip creation.

## 5. Results Discussion

To conduct a statistical analysis of a comparison between three types of sensors, it is necessary to take into account two critical details:

At first, consider both correlation and agreement. There is little consensus in most research since they rely to determine correlation. The inter-class correlation coefficient was utilized to quantify the agreement as well as the repeatability between various approaches [28, 29].

**Table 1.** Computed performance metrics of various sensors

Sensors	Sensor type	Accuracy	Resolution	ICC	Suitable application interpretation	Degree of Agreement
Thermocouple	Invasive	0.1 to 0.5	0.01 to 0.1	0.645	Air temperature maintaining	Moderate agreement
IPRT		0.01	0.01 to 0.1	0.897	Product monitoring	Good agreement
NTC		0.01	0.01 to 0.1	0.746	Integration of product with tooling	Good agreement
	Non-invasive (Thermometry by infrared radiation)	1.0 to 3.1	0.1	0.476	Product monitoring	Poor agreement
	Semi-invasive	0.3 to 0.9	0.1	0.456	Embedded into tooling	Poor agreement

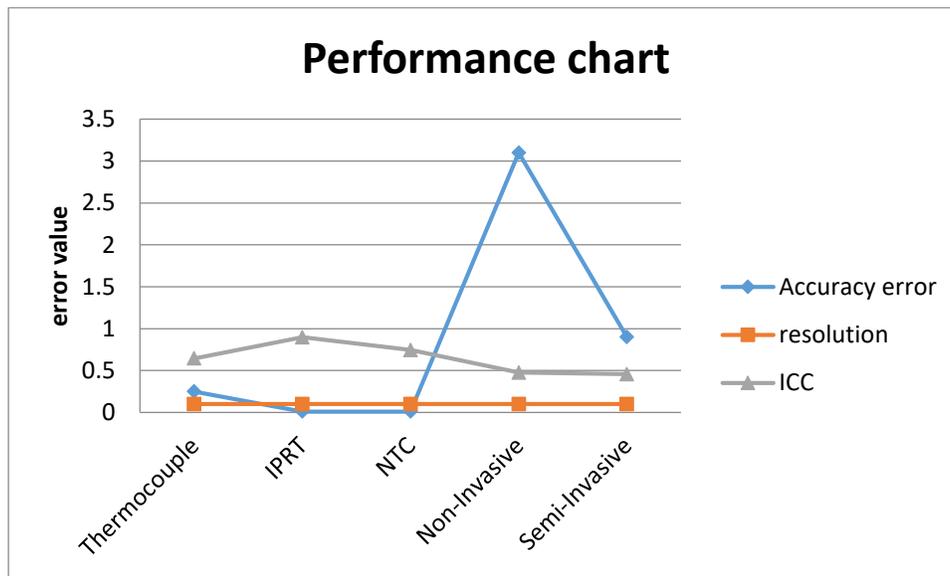
Comparing these three approaches is an excellent way to establish agreement since, unlike other correlation coefficients, it also considers systematic error. Table 1 contains computed result value for various temperature measurement techniques. The determined Inter-class Correlation Coefficient (ICC) of 0.897 demonstrates great reliability for predicting the accuracy error adjustment for the resolution in this investigation, according to the categories mentioned previously. It is defined as,

$$\rho = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_e^2}$$

Where,  $\sigma_s$  is variance between two correlation value

$\sigma_e$  is variance within correlation function

Secondly, it is necessary to assure precision and accuracy with the invasive and non-invasive specification. The invasive method is largely regarded as being in comparable quality to the current gold standard in terms of precision and accuracy, and it is extensively used as such.



**Figure 3.** Overall performance chart

This research demonstrates a good degree of agreement between the oesophagus sensor and the ICC value, extending similar features to the embedded into tooling as well. It is concluded that the degree of agreement is a viable choice when all of the analytical aspects are taken into consideration.

## 6. Conclusion

The modelling of temperature fluctuation has been emphasised as the principal application of thermal metrology in any light controlled factory and in future factories. The uncertainty that temperature measurements impose on the thermal expansion of many common materials has been taken into account. The most accurate way to measure temperature is by using invasive temperature sensors. The semi-invasive and non-invasive sensor types may be easier to use in certain cases, although not always. The development of more cost efficient systems may increase interest in non-invasive technology. The discovery, characterization, and manufacture of high-quality, cheap materials are necessary for temperature-sensing devices. The modelling for measurement uncertainty and large measurement uncertainty components are also crucial. However, to make full use of thermal variation modelling, further work must be done on thermal measurement activities, fusion of thermal metrology, and thermal sensor network architecture.

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