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An Investigation into the Uncertainty of Temperature Measurement in Internet of Things (IoT): A Case Study of Battery Performance Monitoring System for Electric Vehicles

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ABSTRACTS

The value of the uncertainty of the measurement is necessary so that the results of these measurements can be considered whether they are following the needs. In the study of the IoT-based battery performance monitoring system carried out online, the measurement results from the sensors are sent via the internet network to a database which is then accessed, and numerical data processing is carried out. In this system, there are delays from when the data is sampled until the computing device accesses the data, thereby constituting one of the contributing factors to measurement uncertainty. One of the quantities measured in this BMS *(Battery Management System)* is temperature. Too hot temperatures will make the vehicle battery become quickly damaged. In this study, calibration is carried out with measuring methods and equipment traceable to international standards. The results of this calibration are to ensure that the system measurement results used in this battery performance monitoring system are sufficient or not. Estimated uncertainty, the value reported in this calibration, has considered sources of uncertainty in measurements, including time delays in measuring measurements.

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INTRODUCTION

In metrology, measurement uncertainty is an expression of the statistical dispersion of values assigned to a measured quantity. All measurements must have uncertainty, and a measurement result is only called complete if it is accompanied by a statement about the uncertainty, such as the standard deviation. According to the international agreement, this uncertainty has a probabilistic basis and reflects incomplete knowledge of the value of the quantity. Measurement uncertainty is a non-negative parameter[1].

The measurement uncertainty is usually calculated as the standard deviation of the probability distribution with respect to the values that can be assigned to the quantity being measured. Relative uncertainty is the measurement uncertainty relative to the magnitude of a selected value for the measured quantity if the selected value is not equal to zero. This option is usually called the measured value, which can be optimal in some well-defined sense (for example, the mean, median, or

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mode). So, the relative measurement uncertainty is the measurement uncertainty divided by the absolute value of the measured value if the measured value is not equal to zero.

One of the quantities measured in this IoT-based battery performance monitoring system is the battery temperature and the temperature of the battery storage room. The heat effect caused by the current flowing through a conductor causes heat, which is a form of changing electrical energy into heat energy. This energy change is one of the things that must be taken into account to calculate battery performance.

There are several techniques to monitor battery performance, which can be done in situ or online, one of which is calculating battery performance using machine learning algorithms. Computers that have high computing capabilities are needed in this machine-learning calculation. This computing capability is usually not fulfilled by microcontrollers that use low electrical power. In general, the higher the computing capability of a processor, the greater the electrical power required; this makes online processing an option compared to the in situ method because computing devices with high capabilities usually require considerable electrical take, so the computing process on the internet servers does not consume power from the battery of the electric vehicle. In addition, the scalability offered by cloud computing provides a solution to this problem. Cloud computing provides resources at a low cost to its user. Cloud-based smart device monitoring, collection, and data processing platform online monitoring is an option[2][3][4].

METHODS

One of the techniques in sending data is using the Internet of Things, to send data to the destination, it takes time. The measurement results of the measured quantities are sent via the internet and stored in a database which is then processed into input or input for later data processing. This technique causes a delay from one easurement result to the computing device. This delay affects the uncertainty of the measurement results of the measured quantity. In the flow diagram of measurement and data transmission, as shown in **Figure 1**, there is a potential delay when data transmission failure occurs. The more failures, the greater the delay time.

This research was conducted by observing the measuring ability of standard equipment used to calibrate temperature-measuring instruments. The measuring capability of this equipment in the form of an uncertaint value is then estimated and combined with the value of the measuring capability of the temperature calibration system or facility[1][5].

Measurement uncertainty is also known as the uncertainty budget which can be calculated using the formulas below. Processing of thermometer calibration data, with the components of uncertainty taken into account:

1) Re-measurement tool, u_{rep}
2) Standard uncertainty, u_{std}
3) Resolution indicator, u_{resind}
4) Non-uniformity of temperature bath, u_{bath}
5) Standard drift, u_{driftstd}

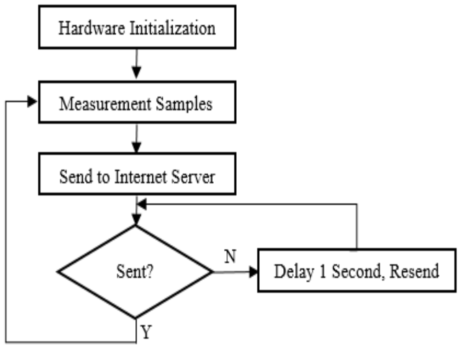


Figure 1. Flowchart of sending data from IoT over the internet

Uncertainty is estimated using the following methods:

A. The standard uncertainty of repeated measurement, u_{rep}, for n readings

$$u_{\mathrm{rep.read}} = \mathrm{STDEV\ (I)}/\sqrt{n} = \mathrm{ESDM} = s, \quad (1)$$

$$s = \sqrt{\frac{\sum_{n=1}^{n}(X_i - \bar{X})}{n-1}} \quad u = \frac{s}{\sqrt{n}}$$

with degrees of freedom, v = (n-1)

B. The standard uncertainty is obtained from the uncertainty of the stretch written in the certificate divided by the coverage factor, K=2.

$$u_{std} = u_{cer}/2, \quad (2)$$

with degrees of freedom, v = 100

C. Resolution indicator

$$u_{\mathrm{resind}} = \mathrm{Resolusi}/\sqrt{3}, \quad (3)$$

with degrees of freedom, v = 60

D. Standard drift, u_{driftstd}, the uncertainty value of the standard drift is assumed to have a rectangular distribution

$$u_{\mathrm{driftsdt}} = U_{\mathrm{drifts}}/\sqrt{3}\ °\mathrm{C}, \quad (4)$$

with degrees of freedom, v = 60

E. Uniformity and stability of bath temperature

$$u_{bath} = \sigma \quad (5)$$

with degrees of freedom, v = 60

F. Uniformity and stability of bath temperature

$$u_{AC} = U_{\mathrm{AC}}/\sqrt{3}\ °\mathrm{C} \quad (6)$$

with degrees of freedom, v = 60

G. The combined uncertainty of the standard calibration results is calculated based on the square root method (RMS) of the standard uncertainties from all sources of uncertainty, namely:

$$u(D) = \sqrt{u_{rep}^2 + u_{std(cert)}^2 + u_{drift}^2 + u_{res}^2 + u_{bath}^2 + u_{ac}^2} \quad (7)$$

Table 1. Uncertainty Budget Table

No	Sources of Uncertainty for Calibration Temperature Measurement	Unity	Distribution	Symbol	Expanded uncert, *U*	Cov. Factor/ Divider	Deg. Of freedom, (*vi*)	Std. Uncert, (*ui*)	Sens. Coeff, (*ci*)	*ci.ui*	(*ci.ui*)^2	(*ci.ui*)^4/*vi*
1	Repeat of reading, u_{rep}=STDEV (I)/ √n = ESDM	^{0}C	Normal	u_{rep}	STDEV	√n	n-1	ESDM	1	$c_i u_i$	$(c_i u_i)^2$	$(c_i u_i)^4$/vi
2	Certificate of standar, $u_{std} = U_{ser}/2$	^{0}C	Normal	u_{std}	u_{ser}	2	100	0.5 u_{ser}	1	$c_i u_i$	$(c_i u_i)^2$	$(c_i u_i)^4$/vi
3	Indicator resolution, $u_{resind} = U_{resind}/\sqrt{3}$	^{0}C	Square	u_{resind}	u_{resind}	√3	60	0.58 u_{resind}	1	$c_i u_i$	$(c_i u_i)^2$	$(c_i u_i)^4$/vi
4	Inhomogeniety & stability of bath, $u_{bath} = \sigma/\sqrt{3}$	^{0}C	Square	u_{bath}	Σ	√3	60	0.58 σ	1	$c_i u_i$	$(c_i u_i)^2$	$(c_i u_i)^4$/vi
5	Drift of standard, $u_{driftstd} = U_{drifts}/\sqrt{3}$	^{0}C	Square	$u_{driftstd}$	u_{drifts}	√3	60	0.58 u_{drifts}	1	$c_i u_i$	$(c_i u_i)^2$	$(c_i u_i)^4$/vi
6	AC pick up, $u_{AC} = U_{AC}/\sqrt{3}$	^{0}C	Square	u_{AC}	u_{AC}	√3	60	0.58 u_{AC}	1	$c_i u_i$	$(c_i u_i)^2$	$(c_i u_i)^4$/vi
						Sums					$\sum_{i=1}^{N}(c_i u_i)^2$	
						Combined uncertenty, *uc*				$\sqrt{\text{sums}} = \sqrt{\sum_{i=1}^{N}(c_i u_i)^2}$		
						Eff. Deg of freedom, V_{eff}					$\frac{u_c^4}{\sum_{i=1}^{N}\frac{u_i^4}{v_i}}$	
						Cov. Factor for 95%				k_{95}		
						Expanded Uncertainty, U95 (°C)				$U = k_{95}$ x $\sqrt{\text{sums}}$		

And the effective degrees of freedom (DOF) is calculated by the equation

$$v_{eff} = \frac{u^4(D)}{\frac{u_{rep}^4}{v_{rep}} + \frac{u_{std(cert)}^4}{v_{std(cert)}} + \frac{u_{drift}^4}{v_{drift}} + \frac{u_{res}^4}{v_{res}} + \frac{u_{bath}^4}{v_{bath}} + \frac{u_{ac}^4}{v_{ac}}} \quad (8)$$

Assuming it has a normal distribution, the coverage factor is at the 95% confidence level, K_{95}. With a stretch, uncertainty equal to

$$U(D) = u(D)\ X\ k_{95} \quad (9)$$

The budget calculation above can be simplified in the form of a table, as in **Table 1**.

RESULTS AND DISCUSSION

Research Results

In general, the working principle of an IoT-based battery performance monitoring system, especially in temperature monitoring, is the temperature sensor measures the heat of the lithium-ion battery then the data is sent to the microcontroller for further processing and sent to the battery monitoring user interface on the computer wirelessly using the 4G (LTE) module. 3G/GSM/GPS connected to the internet. The system design is as shown in **Figure 2**.

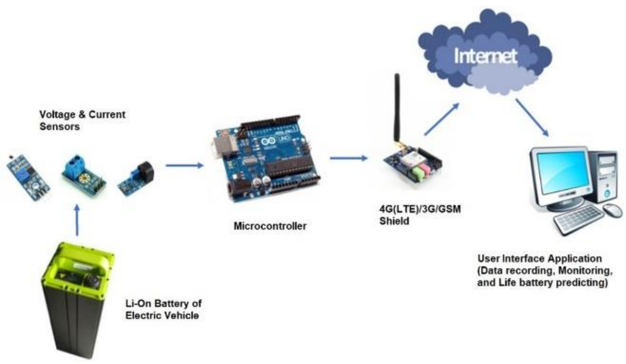


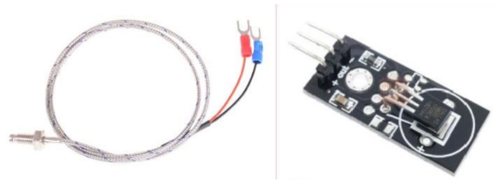
Figure 2. IoT Based Battery Performance Monitoring System

Battery

Figure 3. Li-On Battery without case

Figure 3 shows a lithium-ion battery without a case, the temperature sensor (thermocouple) is placed on the inside of the battery.

Thermometer



(a) (b)

Figure 4. (a) K Type Thermocouple; (b) Thermocouple emf reader modul

Figure 4 shows a thermocouple and an emf reader module used to measure battery temperature. The thermocouple emf reader module is equipped with a temperature meter that functions as a cloud junction. The temperature of the clod junction was set at 25 ^{0}C, so for calibration purposes, it had to be engineered, the module was placed at room temperature of 25 ^{0}C. This thermometer has the best measurement or resolution of 0.1 C. This resolution is good enough for battery temperature measurement.

Temperature sensors work based on physical principles that are affected by changes in temperature. It therefore makes sense for us to study temperature measurement by dividing the instruments used to measure temperature into separate classes according to the physical principle on which they operate. The following are 10 classes of instruments based on their working principles [40]:

- Thermoelectric effect
- Resistance change
- Sensitivity of semiconductor devices
- Radiative heat emission
- Thermography
- Thermal expansion
- Resonant frequency change
- Sensitivity of fiber-optic devices
- Color change
- Change of state of materials

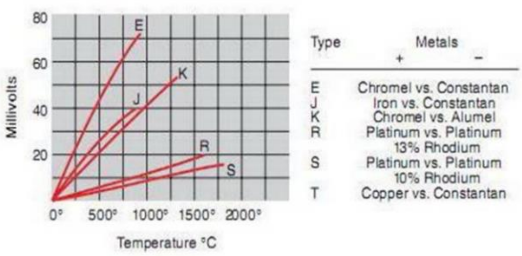


Figure 5. The e.m.f. temperature characteristics for some standard thermocouple materials [6].

Thermocouples are widely used in measuring temperature because they are quite resistant and reliable. Used in industrial environments, placement are easy to engineer, widely available in the market and relatively cheap prices.

The emf-temperature characteristic for some of these standard thermocouples is shown in **Figure 5**. It shows reasonable linearity over at least part of its temperature measurement range.

Temperature calibration facility calibration capability (Uncertainty)

(a) (b) (c)

Figure 6. (a) Standard master equipment (platinum thermometer and display); (b) Thermostat bath with silicone oil media can be used up to 90 ^{0}C; (c) Placement of standard master equipment and calibrated thermometers during the calibration process;

Uncertainty (or measurement uncertainty) is a quantitative measure of the quality of a measurement result so that the measurement result can be compared with other measurement results, references, specifications, or standards.

Discussions

All measurements tend to contain errors in the sense that the measurement results turn out to be different from the "true value" of the quantity being measured. With time and available resources, most sources of measurement error can be identified. Hence, the magnitude of the error can be determined so that the error can be corrected (e.g., by calibration). However, we usually don't have enough time and resources to fully determine and correct all measurement errors.

Measurement uncertainty can be calculated in a number of ways. A method that is widely used and accepted (e.g., by accrediting bodies) is the “GUM method” recommended by ISO and described in the document “Guide to the Expression of Uncertainty in Measurement.” The key points of the GUM method and its basic philosophy are outlined below.

1) A measurand X, whose value is not known exactly, is considered a stochastic variable and has a probability function.
2) The result of x from a measurement is an estimate of the expected value E(X).
3) The standard uncertainty u(x) is equal to the square root of the estimated variance V(X).
4) Type A evaluation: the expected value and variance are statistically estimated from a set of measurements.
5) Type B evaluation: the expected value and variance are estimated in other ways. The most common method is to assume a probability distribution, such as a square distribution, based on experience or other information.

Table 2. Budget Component Uncertainty Value

No	Component Budget	Unit	Distribution	Value ±
1	Standard thermometer certificate with a platinum sensor	^0C	Normal	0.0200000000
2	Standard drifts	^0C	Square	0.0049250000
3	AC pick-up	^0C	Square	0.0000000000
4	Standard repeat measurements	^0C	Normal	0.0010327956
5	Non-uniformity & stability of tub temperature	^0C	Square	0.0392408132

Measurement Traceability

Measuring equipment (including thermometers) must be traceable to the International System of Units, SI. Namely that the measuring instrument has been calibrated, or tested for accuracy by comparing it with equipment with a better level of accuracy.

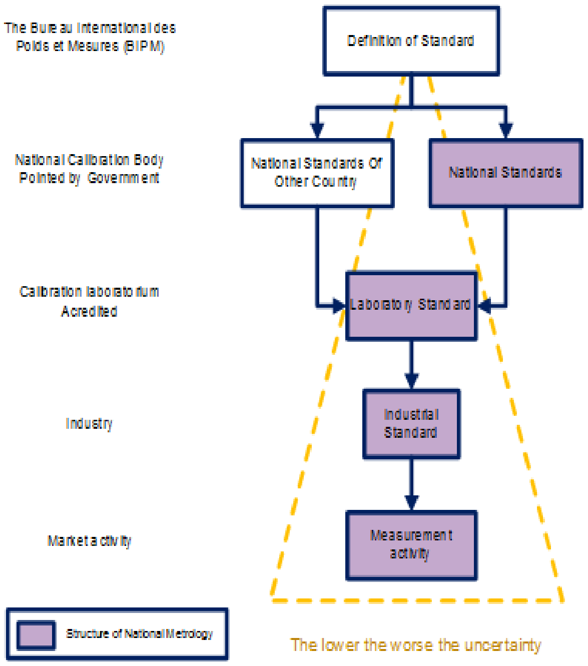


Figure 7. An unbroken chain of several comparisons

Table 3. Estimation of Uncertainty or Estimation of Measuring Capability of a Temperature Calibration Facility

UNCERTAINTY BUDGET	
Sums	**0.0006214723**
The combined uncertainty, uc	**0.0249293472**
Eff. Deg of freedom, veff	**85.980542485**
Cov. The factor for 95% CL	**1.99**
Expanded Uncertainty, U95 (°C)	**0.0495662209**

A traceability chain, as in **Figure 7**, is an unbroken chain of several comparisons, each of which is represented by uncertainty. This ensures that a measurement result or value from a standard is linked to a higher reference, and so on, up to the primary standard [2].

The measurement uncertainty of each step in the traceability chain must be calculated according to a defined method. It must be expressed at each step so that the total uncertainty of the entire chain can be taken into account.

Based on the measurement data, each budget component's uncertainty value is obtained, shown in **Table 2**. A calibration facility is obtained to estimate uncertainty or the measuring capability of a temperature, which is shown in **Table 3.**

CONCLUSION

From the results of the calibration that has been carried out, a stretch uncertainty value of 0.05 C is obtained with a coverage factor of 2.0 and a degree of freedom of 86, where this value is obtained at a 95% confidence level. These results indicate that the temperature sensor and IoT used to have a measurement uncertainty that is better than the expected target, below 2%. The delay in the data transmission process has no significant effect because the thermostat tub used has good stability, so the temperature at the time of calibration is relatively constant at 4-second intervals, which is the average delay time. So the results of this temperature research and calibration, it can be concluded that the value of the thermocouple calibration results can be applied to the measuring instrument to be used.

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