A New Instrument Enriched by Type A Uncertainty Evaluation

Marian Jerzy Korczynski[1], Zygmunt Lech Warsza[2]

[1] Technical University of Lodz; Stefanowskiego 18/22, 90-924 Lodz, phone: +48516087570;
fax: +4842 662281, e-mail: jerzykor@p.lodz.pl
[2] Polish Metrological Society Warszawa, phone: +48692033661; phone/ fax:: +48227565510;
email: zlw@op.pl

Abstract- An idea of the new type of instrument, improved by pre-processing of the measurement data is presented in the paper. This instrument has an extensive data handling procedures, which allow to investigate different periodical and non-periodical components in raw data and to clean the data from identified influences. Such cleaning upgrades the type A uncertainty evaluation.

I. The Challenge

In raw collected measurement data, may exist some unknown periodical and non periodical components, which appear in an object under investigation or in an measurement instrumentation. The widely internationally accepted Guide to Uncertainty in Measurement, GUM, and its actual and proposed Supplements [1-3], [6] do not refer to treatment of raw collected data before procedure of type A uncertainty is applied. Such a pre-processing of raw data, was presented in the paper presented at IMEKO TC4 2007 Symposium in Iasi [7]. Proposed data pre-processing refers to either regularly in time sampled data or collected in known moments in time. Based on method proposed in [9] the virtual instrument which facilitates a man, who run en experiment is developed and the results of application are presented in the paper.

The idea is based on investigation of a priori unknown periodical and non-periodical components in data before uncertainty of type A calculation is applied. These components may be treated as disturbances in data, which deteriorate picture of type A uncertainties. These disturbances can be induced and represent physical processes like short term instability or variation of instrument parameters caused by internal or external influences. It can also be caused by instability of source of signal under investigation.

Many digital instruments have build up, software based measurement functions like FFT, filtering averaging, etc. for series of collected data, but calculation of uncertainties, including analysis of series of sampled data in the form of data analysis to calculate uncertainty is not presented jet. The authors of the paper enriched already developed by Korczyński and Hetman [3] instrument by implementing by the ideas of data treatment proposed by Dorozhovetz, Warsza, presented in papers [6, 8] and further development jointly with Korczyński in [7]. That theoretical works are referred to data cleaning from unknown a priori systematic disturbances, which are identified as periodical and non-periodical components. The effectiveness of the proposed methods was presented, by applying simulated and real data from experiments.

The developed instrument would be especially useful in technical diagnostic systems and medical testing instruments as well as in control systems in which different parameters are subjected to variation induced by internal or external influence. All theses application require not only to measure the value of a signal but also uncertainties. The measurement parameters in diagnostics and medical tests are very often subjected to environmentally caused disturbances in measurement. Measurements may be performed in highly interfering environment and useful signal may be lower than induced disturbances. In such situations the filtering of signals is required and handling of raw data is an appropriate procedure.

II. Background

The *Guide to the Expression of Uncertainty in Measurement*, called Guide [1] is worldwide applied in everyday metrology practice in evaluation of uncertainties. In basic terms, used in Guide, there is not the true value used any more, as it is unknown in fact. To increase the measurement accuracy, the series of n repeatable measurements is recommended. The *n* measurement results of q_i are representing

raw corrected values. The arithmetical mean of series of observations of measurand of X is recognized $\overline{x} \equiv \overline{q}$ as the best estimate of the population of their possible values. Evaluation of overall uncertainty U is based on calculation of two components $u_A(x)$ from the series of observations in which standard type A uncertainty equals to standard deviation $s(\overline{q})$ corrected sample of observations and type B component $u_B(x)$, which comes from other than series of measurements and have an heurist approach.

The type A uncertainty relates to statistical dispersion of measurement results as type B replaced in some way the "error theory" in which worst case of error played a key role. The next step after calculation of u_A i u_B uncertainties is calculation of joint distribution of both components as earlier the distributions for both type A and type B methods are assigned. The GUM recommends calculation of combined uncertainty as geometric mean $u_c(x) = \sqrt{u_A^2(x) + u_B^2(x)}$ and expanded uncertainty $U(x) = k_p u_c(x)$, in which k_p coefficient is statistic variable and for $p = 0.95$ is in general in the range from 2 to 3. The methods of calculation of types A and B uncertainties are quite well described in literature. GUM recommendation [1] is based on several assumptions like:

1. treatment of the sample observations as statistically independent after elimination of systematic components
2. observations are uncorrelated and of equal weights
3. Parameters as: mean value $\overline{x} \equiv \overline{q}$ and standard deviation $s(\overline{q})$ calculated based on series of observations are calculated based on assumption that observations are normally distributed and calculated parameters from sample are representing population

Wider applying Guide's recommendations GUM come across on limitation in many scientific investigations and usable, particularly in industry and exploitation, because:

- do not take into account of inaccuracy caused by incompletes of the measurement model and measurement chain,
- collected raw observations, even after correction by well-known values, are not jet purely random variable of the sample, because observations these may contain the unknown a priori components, of which nature is a systematic disturbances caused by different external and internal physical effects,
- the dispersion of observations are assumed to be random variable, but rather the stochastic approach to the process should be applied as the order of observations and statistical autocorrelation should be taken into account as it is proposed in [6, 8],
- the dispersion of value of observation can be better represented by other then normal distributions, for which more adequate are other estimators than arithmetic means and her standard deviation in such cases the centre of distribution for rectangular dispersion, the median for two - the exponential distribution of the Laplace [6, 8].

The implementation of algorithms in software of instruments would result that the experimenter would get on line not only a single measurement result but also the estimated uncertainty calculated in general according to GUM recommendation. Some still to encountered aspects should be approached and get a solution in practice as: improvement of methods, which were described by Dorozhovetz and the Warsza, like detecting and cleaning of measurement results from periodical and non periodical disturbances, and so called "outliers", applying the method elaborated by Paveze and Ichim [4].

It seems that nowadays development in uncertainty evaluation could be carried on further GUM improvement by recognition of new methods and data treatment at the early stage of data handling jus after data collection.

III. Proposal of improvement of type A method evaluation

In practice, in many industrial measurements and diagnostic investigations (tests), beside random disturbances, appears usually difficult to eliminate unknown a priori disturbances of deterministic nature. These disturbances effects dispersion of measurement results of not having random character. Such situations are consider below.

If for determination of the certain value x, the n measurements uniformly in time $t = t_i = (i-1)\Delta T$ are collected, then i sample is assigned to $t = t_i$ and:

$$X_i = x + f(t_i) + e_i \qquad \text{for } i = 1,2,\cdots,n$$

where: $x \in R$ (R – real number), $f(t)$-unknown a priori deterministic function, X_i -observed value in i - observation, e_i - independent variable describing random dispersion of observations

The source of systematic influence described by $f(t)$ and random dispersion $e(n)$ is the tested object and the instrumental measurement chain and its elements on the signal flow. Based on observations: $x_1, x_2, ..., x_n$ of random variable. After considering (deducting) the known corrections the corrected observations were received as: $q_i = X_i - f(t_i)$, $i = 1, 2, ..., n,$

As in practice, the functions: $f(t), e_i$ are of not known type, and the due to a great variety of analysed parameters and quantities, mainly in technical and industrial measurements, the single method using schematic mathematical statistics approach is too laborious or not possible. In many cases it is appropriate to recognize the e_i function normal distribution, or other, of which best estimate of measured quantity is mean of corrected observations q_i. The standard deviation of mean $s(\bar{q})$ is the best estimate of standard uncertainty. But in each measurement process, the $f(t)$ function depends on different parameters and many influential quantities, and moreover cannot be removed by simple data correction.

If the GUM procedures are applied for such uncorrected data, the distribution to not comply to the requirements of random Normal distribution, standard uncertainty is overestimated, and the error of evaluated can be easily several times bigger then after applying procedures of data cleaning from such disturbances.

The proposed methods of data handling consistent to GUM recommendation are proposed in [6-8] and the scheme of is in Fig. 1
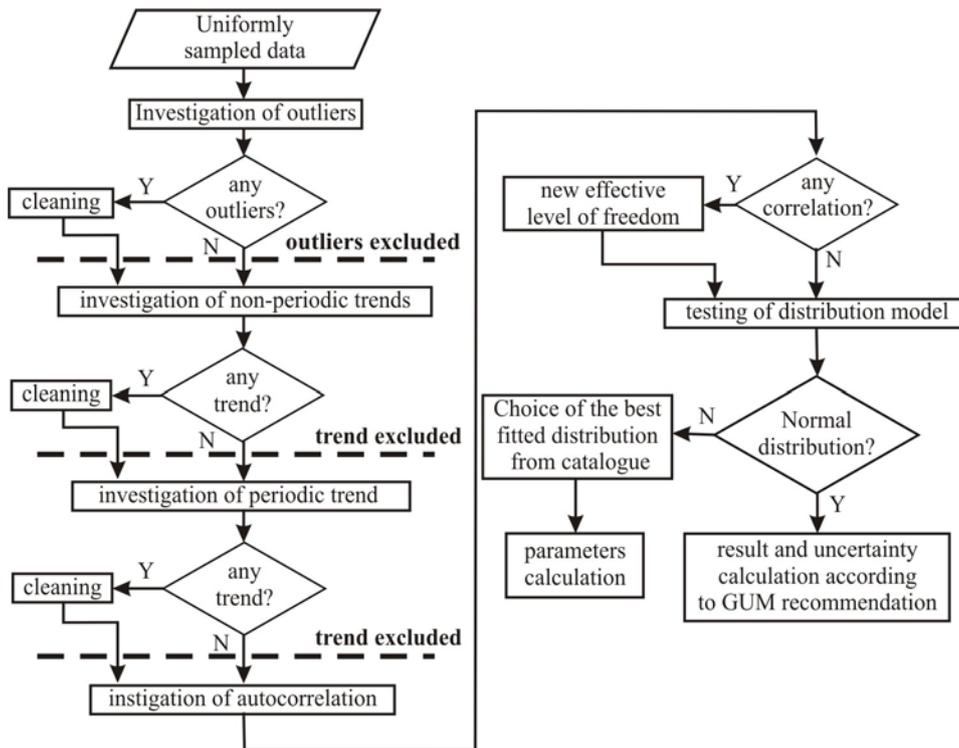

Figure 1. Block diagram of data handling for data clearing from periodical and non-periodical components is data for upgrading type uncertainties.

IV. Examples

Example I. Uncertainty u_A estimation of the DC voltage in the circuit with sinusoidal distortion.
In Fig 2 the measurement system with extended data procedures for Type A uncertainty evaluation is connected to the galvanic stable source of voltage and sources of disturbances in which amplitude and frequency are adjustable. So the periodical disturbances are under controls, in the limited range, but still it is better to have such information than no information at all for check in the procedures.
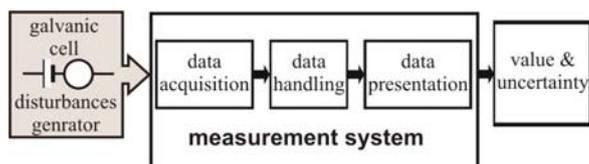
Fig 2. The application of measurement system with data cleaning procedures for evaluation of the DC voltage type A uncertainty
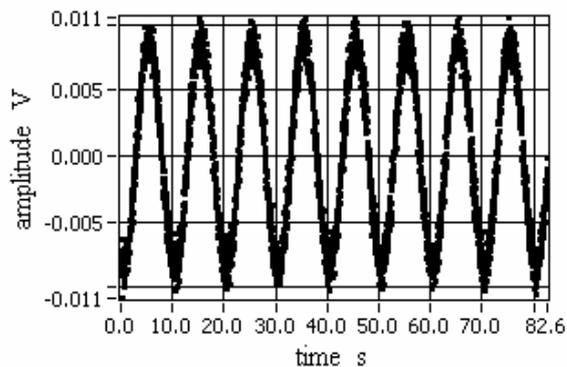

Figure 3a. Raw experimental data collected from experiment using NI DMM 4060 men value 1.01735 V in which periodical disturbance is observed
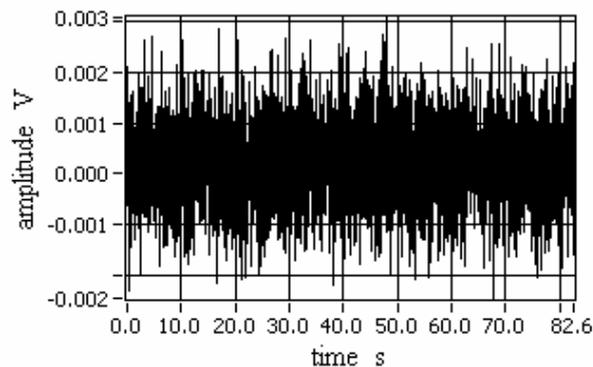

Figure 3b. Raw data after cleaning from sinusoidal disturbance of the identified frequency of 0.10088 Hz
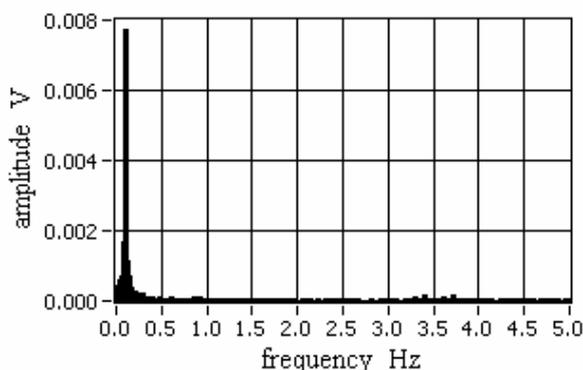

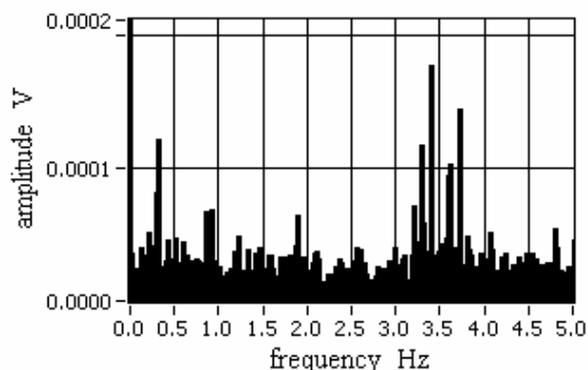Figure 3c. FFT of raw data in which a dominating frequency was identified (f=0.10088 Hz)

Figure 3d. FFT of raw data after cleaning from dominating frequency, no other dominating frequencies observed.
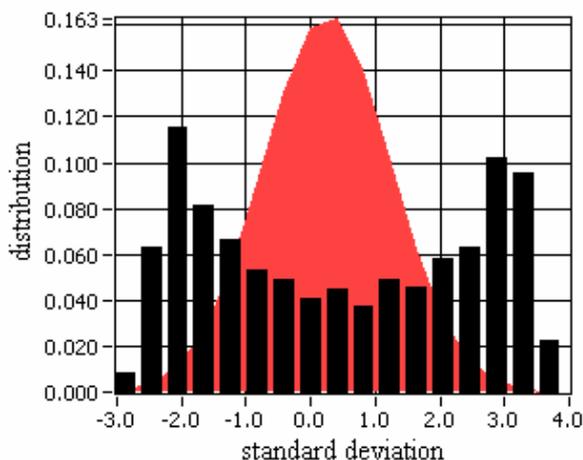

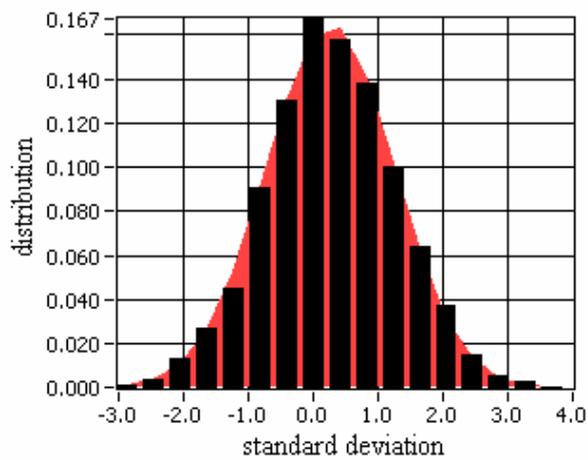Figure 3e. Histogram of raw data (white colour) an optimal Normal distribution (red)

Figure 3f Histogram of raw data after cleaning from periodical disturbance (white colour) an optimal Normal distribution (red)

The measurement system consisted of DMM NI 4060 of the accuracy $0.017\% \pm 10\mu V$ and LabView ^{R} as G language which supports implementation the procedures for both cleaning and uncertainty evaluation. The experiment in which was adjustable source of disturbances of sinusoidal shape has an privilege over non-controlled, as for pretty stable constant voltage source as in Fig. 2, this value is stable and not influenced by any variations of inferior and external disturbances for our goals of the experiment, was treated as true value.

Example 2. Testing of acoustic generator stability
In Fig. 4 the block diagram presents the experiment of the acoustic signal generator stability investigation..
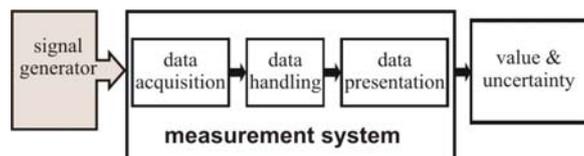

Figure 4. The application of measurement system (instrument) with data cleaning procedures for evaluation of uncertainties of type A for investigation of stability of the generator

The measurement system consists in this case of K200 Keithley 6 ½ digital voltmeter of accuracy 0.06 % of measured value and 0.03 % of the rage value (10 V range was applied in this case)
$$\Delta_{lim} = 0,06\ \% \cdot 6.54\ V + 0,03\ \% \cdot 10,00\ V = 6,924\ mV \quad u_B = \frac{1}{\sqrt{3}}\Delta_{gr} = \frac{1}{\sqrt{3}}6,924\ mV = 4,000\ mV$$

In Figures 5(5a-5d) the measurement results are presented for voltage amplitude of 1000 Hz of generated signal and for two different periods of sampling.
The results presented in Fig 5a-h refer to investigation of the stability in time for period of investigation lasting 34'06".
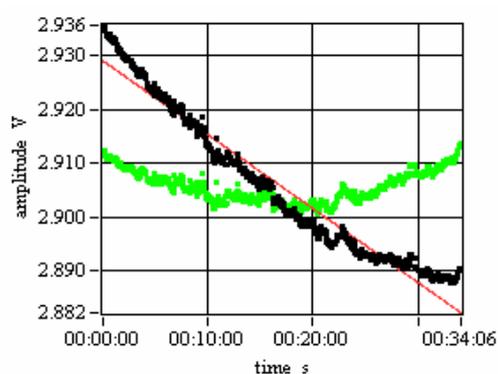

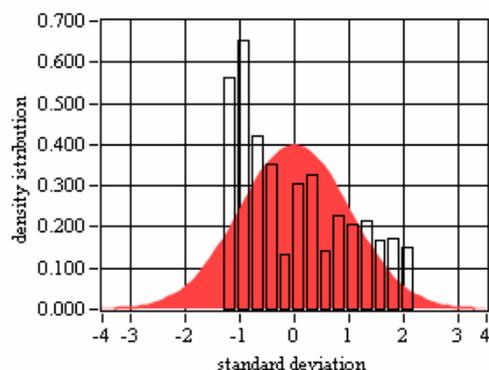Fig. 5a. Raw data linear trend line and data after cleaning from the trend

Fig. 5b. Raw 2nd order polynomial trend line and data after cleaning from the trend

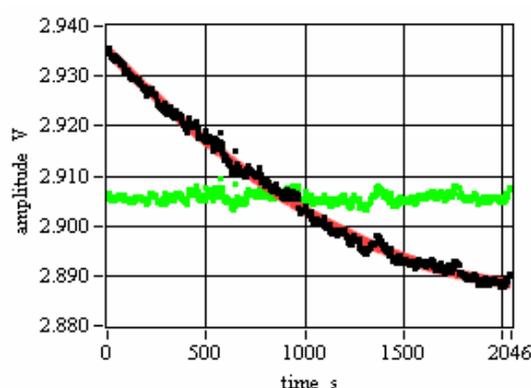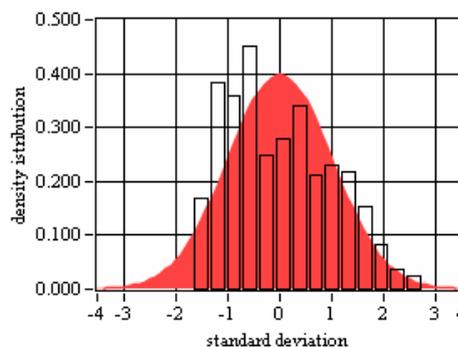Fig. 5c. Histogram of raw data (very far from Normal distribution)

Fig. 5d. Histogram of data cleaned from linear trend and its Normal distribution (according $\chi 2$ criterion)

Presented method of upgrading calculation of raw data treatment during long term and short term periods, seems to useful and promising. There is possible to increase the quality of measurements by reduction of periodical and non periodical trends. From above tests is possible to conclude, that long term tests should have a set of shorter periods in which data are sampled faster, like here 10 times.

Conclusions

Presented here was the first stage of work on a new type of instrument which gives the actual measurements and assesses their uncertainties [7]. It indicates that the automation of calculation "on line" of uncertainty of type A demands a specialized software of calculations and decision making, shown in Figure 2. These are:

- Determination of the separation distance between observations in the sample in time, space coordinates, or as functions of other parameters.
- Search and clean of the data of non-periodical unknown and undesirable components e.g. periodic and non-periodical, linear and nonlinear, when determining a constant, and periodic and nonlinear when determining a straight line etc.
- Automatic counting and allowing for the influence of autocorrelation of observations.
- Finding the optimal distribution of observations model and determining optimal ALTERNATIVE estimators to those given by GUM (Figure 3f - the presentation of real distribution, its model and its the best estimators)
- Further stages will include: automatic determination of "on line" total uncertainty with possibility of typing in of uncertainty data determined by heuristic method type B [4, 5, 9]. This will include measurements of a single value, as well as intermediate parameters.
- A number of additional tasks will show up when the automatic estimation of uncertainty type A is concluded.

References

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