# The measurement uncertainty and validation of automatic unmanned noise monitoring installations

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## Introduction

At this moment there are more and more unmanned automatic working noise monitor installations. They automatically select undesirable noises and produces useful parameters. The most used application is measuring aircraft noise and industrial noise. But also other activities are monitored like pop concerts, motorcycle circuits, motor ways and railway yards. The main advantage of such an installation is saving costs and manpower and larger sampling of continuous noise. Also noise incidents can better be detected.

An important aspect of this kind of measuring is the measurement uncertainty caused by errors in the noise selection process and the equivalency to a manned measurements. At present there is no national or international acknowledged validation method. I this article two different methods are described.

## Measurement standards

In the Netherlands we have known since more than 25 years a number of measurement guides prescribed by the law called " Reken en meetvoorschrift Geluidhinder 2006". (calculation en measurement guide noise annoyance 2006) In this guideline is stated about special measuremen metods: *There may be no influence of background noise.*

In several ISO standards it is frequently put that if the background noise level is more than 10 dB below the imission level, the influence of back-ground noise can be neglected. This means a back-ground noise correction of no more than 0,413 dB .

## Aircraft noise

In the field of aircraft noise no measurement standard exists in the Netherlands. Internationally there is a concept measurement standard ISO-DIS is 20906 "Unattended monitoring or aircraft noise in the vicinity or airports" of 29-2-2008. With respect to the event detection three criteria are called:

1 *The expanded uncertainty of the measured cumulated exposure level of all aircraft noise events shall not exceed 3 dB.*
2 *At Least 50% of true aircraft sound events shall be correctly classified as aircraft sound events*
3 *The number of non-aircraft noise events which are incorrectly classified as aircraft noise shall be less than 50% of the true number or aircraft sound events.*

*The test period shall include at least 20 aircraft sound events of the same type or aircraft operation each or which produces an AS-weighted noise level 5 dB above the level of the background sound.*

The criterion of 3 dB seems very large. But the largest deviation has been attributed to uncertainties in the propagation of the noise through the air. For the uncertainties by the background noise just are some tenths of decibel available.

The criterion of noise events correctly classified of 50% seems also to be very wide. In practice the loudest half of the noise events must be well classified. This contains normally 95% of the total noise energy. The other half counts only 0.2 dB in the total noise level.

**Figure 1:** Aircraft noise monitoring station "Luistervink" with low microphone, sound absorbing bottom and automatic noise selection software.

## Standards measurement uncertainty for the environment

Concerning the measurement uncertainty and equivalent measurement methods in the environment sector recently two Dutch standards have been published: the NEN 7778 in July 2003 "Equivalence of measurement methods" and the NEN 7779 in February 2008 "Environmental measurement uncertainties". Although these standards are made for the chemical laboratory, from them a suitable testing method for noise measurements can be developed. We call this the black box method.

## Black box method

This method can be done in a few steps: First carry out a number of measurements under different circumstances with two independent measurement systems : a reference method and the candidate equivalent method. Then calculate the difference $d_i$ between the resulting noise levels of both methods. In the next step calculate the energetic average $d_g$ of all the measurements according to:

$$d_g = 10\log\left(\frac{1}{n}\sum_{1}^{i=n} 10^{\frac{di}{10}}\right) \quad \text{[dB]} \qquad (1)$$

Then calculate the standard measurement uncertainty *u* of the differences according to:

$$u = RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{i=n}\left(d_i\right)^2} \qquad [\text{dB}] \qquad (2)$$

finally calculate the so-called expanded uncertainty $U_{95}$ that at 95% coverage factor k of 2 two times the standard measurement uncertainty.

$$U_{95} = 2 * u + d_g \qquad [\text{dB}] \qquad (3)$$

If corrections are being made for the systematic deviation, the *dg* can be put on zero.

## Equivalence criterion

The *U95* has to be equal or less than 0.41 dB. The procedure is simple, but the implementation details are very important.

## Choice of acoustical parameter

The parameter depends on the type noise. At industry noise, traffic and railway noise are considered the $L_{day}$, $L_{evening}$ and $L_{night}$. At aircraft noise is that the $L_{den}$ over a year.

## Reference measurement

The best form of reference method is manned measurements. Hereby the selection of disturbing noise is done by a human being and the measurement is paused when disturbing noise occurs. This is reliable, but time consuming.

An useful practical alternative measuring method is a semi-automatic unmanned noise measuring systems which automatically records all noise events which exceeds the L95 background level with a certain noise level. It would be useful to make a sound record at the same time. There are several monitor systems available which have these properties. Both measurements can contain extra parameters like recordings of auxiliary microphones, magnetic loops, radar information etc.

It is essential the classification of the disturbing noise is done by a human being with 98% reliability.

## Representativity

The circumstances during the validation measurements must be representative for the whole year and contain all possible circumstances. That applies especially to the presence of disturbing noise. An exploration of the type of disturbing noise must be carried out because it can be different per location. Examples of various types are: wind quivering, traffic noise, human votes, music etc. The test however is only valid for the examined location.

## Coverage

According to the NEN -7778 and 7779 and the ISO/DIS 20906, which are based on the ISO Guide 98 guide to the expression or uncertainty in measurements (GUM) a probability of 95% must applied to the measurement uncertainty. This also means a validity of 95% of the measurement time. 5 % of the time the criterion is not met. In the case of industrial noise with 250 days per year operational time, this 5 % means 13 days. In the Netherlands these 13 days can be considered as exceptional with other noise limits.

## Number and duration of the test

In the NEN 7778 and ISO 5725 it is prescribed minimum 8 samples to take. The duration of each test is preferably equal to the duration of the noise parameter: the whole daily, evening or night period. This can cause practical objections. Shorter measurements are possible. A shorter test duration would be statistically seen admissible because the uncertainty of the average of a short measuring period is larger a long measuring period. A short validation period results in a safe approach provided that the validation period is representative.

## Unwanted variances Report

A disadvantage of the black box method is that there are a number of uncertainties in the total variance $u^2$ that has nothing to do with the errors in the selection capacity and normally are the same for reference and candidate method. Below a number of them are mentioned:

$$u^2 = u^2_{microphone} + u^2_{sound\ level\ meter} + u^2_{calibation} + u^2_{propagation} + u^2_{noise\ source} + u^2_{selection} \qquad [\text{dB}] \qquad (4)$$

It is better to reduce the number of unwanted uncertainties by measuring on the same location at the same source at the same time with the same microphone and noise level meter and calibrate with same the calibrator.

## Analytical validation method

Beside the black box method also another method can be followed which only looks at the errors in the classification process of the noise events. This has the advantage of no influence of unwanted uncertainties of source, propagation, microphone, calibrator etc. It is also possible to analyse the classification process for development purposes.

The following conditions are important:
-1-The recorded noise levels must be divided in separate noise events which can be classified by the unmanned system and by the candidate monitoring installation. Aircraft-traffic and railway noise events are simple to recognize. Continuous industrial noise events can be more difficult to define. But disturbing noise is mostly not continue and only has to be recorded when it exceeds the immision level. Sometimes auxiliary microphones have to be used. The noise events of both measurements must be synchronised.
-2-The candidate monitor system must meet all requirements of the measurement standards in a separate procedure because the analytical method only looks at the selection process of the candidate system.
-3- The calculation has to be done in anti logarithmic sound energies according to:

$$E = 10^{\left(\frac{LAE}{10}\right)} \qquad (5)$$

Where LAE = the sound exposure level of the noise event

## Procedure

1) Determine from the noise levels the noise energy of each noise event of the automatic- and the reference measurement.
2) Classify each noise event in the class source noise, and background noise with the candidate and the reference measurement.
3) calculate the total noise energy of the noise events in the following classes:

*Esg* well classified source noise events
*Edg* well classified disturbing noise events
*Esf* false classified source noise events
*Edf* false classified disturbing noise events

Both errors *Esf* and *Ebf* work contrary, compensate each other partially and are in principle independent. The maximum error in the final result appears when one error is maximal and the other one is minimal.

The measurement bias of the candidate installation is calculated by:

$$dL_{error,j} = d_j = 10 * \log\left(\frac{\sum E_{df} - \sum E_{sf}}{T_{valid}}\right) \text{ [dB]} \qquad (6)$$

## Valid measurement time

The measurement time is only valid if there is no influence of background or disturbing noise. During the manned measurement there must be paused during presence of disturbing noise. In the case of unmanned monitoring the paused time can be implemented by reduction of the total measurement time with the duration of the disturbing noise. This is defined as invalid time $T_{invalid..}$ Also when the installation is not operational the time is invalid. The valid measurement time has to be calculated:

$$T_{valid} = T_{total} - \sum T_{invalid} \quad \text{Sec} \qquad (7)$$

## Selection capacity

The selection capacity is calculated by the quantity of disturbing noise which enters the system, divided by the quantity which remains after selection:

$$\Delta L_{selection} = 10 * \log\left(\frac{\sum E_{dr} + \sum E_{df}}{\sum E_{df} - E_{sf}}\right) \text{ dB} \qquad (8)$$

The selection error Dj is calculated for each of the 8 different measurements. Then the average difference $d_g$ is calculated and the standard uncertainty *u* of the differences according (1) and (2) .

The extended uncertainty *U95* with 95 % probability is equal to:

$$U_{95} = 2 * u + d_g \quad \text{[dB]} \qquad (9)$$

If corrections are being made for the systematic deviation, the *dg* can be put on zero.

The automatic unmanned monitor system is equivalent to manned measurements when the *U95* is equal or not larger 0.41 dB.

## Restriction of validation

If the candidate method has not the same operational range with respect to whether conditions etc. as the reference method, it is not 100% equivalent. In that case the restriction must be indicated clearly.

## Report

The validation report should contain at least the following information:
- the reference procedure
- the candidate equivalent procedure
- the research period
- the name of the responsible research worker and institution
- the compared performance characteristics
- the specified validation procedure incl. equipment and appliances
- the original measurement results and the circumstances among which these have been obtained
- the calculation method
- the results
- a reference to the used standards

**Fig 2** Industrial noise monitoring unit with auxiliary microphone inside the box.

## References

NEN 7778-2003 equivalences of environmental measurement methods
NEN 7779-2008 environmental measurements uncertainties
ISO/DIS 20906.2-2008 unattended monitoring or aircraft noise in the vicinity or airports.
Measurement Guide for Industrial Noise 1999, ministry of environment of the Netherlands VROM, ISBN 90 422 02327