ON THE USE OF SMARTPHONES FOR OCCUPATIONAL NOISE MONITORING: INSTRUMENTATION

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ABSTRACT

This paper presents an on-going research effort that focuses on a smartphone-based occupational noise monitoring platform. A laboratory calibration method for smartphones and embedded devices, together with an innovative "field" calibration are detailed. The evaluation of uncertainties associated with the use of smartphones for noise level measurement is discussed with regards to the main individual uncertainty components.

1. INTRODUCTION

Although noise induced hearing loss represents the number one occupational disease, individual workers' noise exposure levels are still rarely precisely known and infrequently tracked. Indeed, standardized noise exposure campaigns have as their principle disadvantages the cost of instrumentation and the practical difficulties associated with real world implementation. In opposition to these procedures, informal noise surveys carried out with basic and inexpensive sound level meters are not necessarily precise or accurate enough.

The *WikiLeq* project [1] proposes the use of smartphones as an alternate solution. The first step of the project focuses on the evaluation of the measurement quality through the assessment of uncertainties associated with the instrumentation. In a second step, the uncertainty associated with time and spatial sampling strategies for noise exposure assessment will be carefully evaluated.

2. ANDROID IMPLEMENTATION

WikiLeq is an open source framework for monitoring occupational noise based on the NoiseTube project [2]. It combines two simultaneous approaches: the first one features a personal full work shift dosimetric assessment, while the second features a participative sound pressure levels mapping.

An Android™ (v2.3.5) application has been developed for the personal full work shift dosimetric assessment: A-weighting and real-time octave band filters (63 to 8,000 Hz) have been implemented for a 16-bits audio stream acquired at 22,050 Hz. This application requires the user to define what type of microphone device is used and where it will be located on the user's body; an associated *calibration adjustment* is determined and applied to the measured L_{eq}. One-second octave-band equivalent level, $L_{eq,1s}$, are then computed and tagged with GPS data. A cumulative long-term L_{eq} is displayed within the application and will be in near future presented with the associated expanded measurement uncertainty (detailed in Section 4). Finally, the locally stored data is sent to the *WikiLeq* server for data aggregation required for the participative sound pressure levels mapping.

3. CALIBRATION PROTOCOLS

3.1. Laboratory calibration

This procedure, based on IEC 1183 standard [3], aims at separating the diffuse field sensitivity levels associated with the directional characteristics of a device from the one associated with the effects of its mounting position. The resulting *random-incidence calibration value*, regroups these two effects, and will be determined for a wide range of noise levels for one specific microphone device among supported by the WikiLeq application such as the phone embedded microphone, the "in-line" microphone on headphone cord and the microphone of a Bluetooth® earpiece.

- Random Incidence Microphone Placement Error

In a reverberation room, the reference microphone measurements, conducted on a head and torso simulator (HATS) at different mounting positions are compared to measurements done with the same microphone at the center-of-head position without the mannequin. Acoustical reflections and mannequin shielding effects lead to a random-incidence microphone placement error, ε_{mp} , that can be measured for every octave band at typical microphone positions: on the belt holster, in the breast pocket, on an "in-line" headphone cord and on top of the shoulder, as per ISO 9612 standard [4].

- Random-incidence sensitivity levels

The random-incidence sensitivity levels, G_{RI}, are calculated for each octave band from Eq. 1 below and measured in a semi-anechoic room. The free-field sensitivity level, G_F, is measured for a reference direction of sound incidence and directivity factor, γ, assessed from an IEC 1183 procedure.

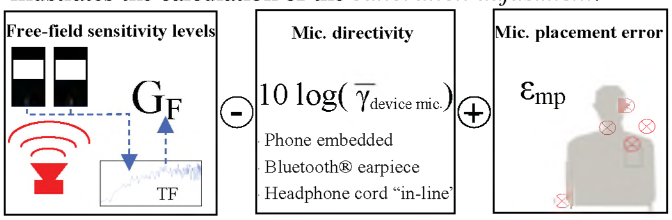
$$G_{RI} = G_F - 10 \log (\gamma) \qquad (1)$$

- Calibration adjustment

The obtained G_{RI} values are stored in the *WikiLeq* application calibration module and will be added to ε_{mp} to obtain a so-called octave-band *calibration adjustment* specific to the microphone device used and its mounting position.

3.2. Field calibration proposed approach

A laboratory calibrated smartphone will now be used to calibrate an uncalibrated microphone device in the field by assessing its free-field sensitivity levels with the following proposed approach: the calibrated and uncalibrated phones are physically brought close together to be immersed in the same sound-field and a real-time audio recording is performed. A dual channel FFT analysis, implemented in the Android "app", will estimate the transfer function between the two microphone devices and compute a free-field sensitivity levels, G_F, for the device under field calibration. The normalized random error for the frequency response magnitude is calculated from the coherence function in order to evaluate the quality of that field calibration. The values of G_F, are then stored in the newly calibrated phone app with an associated "field calibration uncertainty" that quantifies the quality of the proposed field calibration. An average directivity factor, $\bar{\gamma}$, for the three types of microphone device is calculated. The figure illustrates the calculation of the *calibration adjustment*.



(a) (b) (c)

Fig.1. Calculation of the *calibration adjustment* with the field calibration values; assessing free-field mic. sensitivity relative to calibrated device (a), then accounting for mic. directivity (b) and mic. placement position (c).

4. INSTRUMENTATION UNCERTAINTIES

4.1. Main uncertainties considered

Prior published analysis on noise dosimeter and sound level meter measurements uncertainties has been revisited for the envisioned use of a smartphone. For a large population of IEC-compliant noise dosimeters, 4 main uncertainties [5] are given: microphone placement errors, frequency response errors, linearity and sensitivity errors. On top of these, the uncertainties associated with the *WikiLeq* lab and field calibrations as well as the long term environmental and aging drifts need to be considered.

- Microphone placement error is partially addressed in the *calibration adjustment* calculations. In a free-field situation (with a source at a particular angle of incidence) the microphone placement error will be underestimated [5]. It is reduced when the worker is mobile with respect to the noise source [5].
- Frequency response uncertainty is principally influenced by the data acquisition hardware (microphone, pre-amplifier,…) since A-weighting and octave-bands filters are digitally implemented. The quality of the laboratory calibration process impacts significantly this uncertainty.
- Linearity and sensitivity uncertainties are due to the discrepancies between the measured sound pressure level and the reference sound pressure level for a 30 dB range over 90 dB sound pressure level (at which sensitivity is assessed). Again, the quality of the laboratory calibration process impacts significantly this uncertainty while it rises naturally at higher noise levels because of the stalling "slope" of the calibration response curve.
- Laboratory calibration error, ε_{mp} , may lead to an error since it is measured without considering the directivity of the microphone under calibration. Uncertainties associated with the "laboratory" measurements of the sensitivity levels and directivity factors must also be taken into account.
- Field calibration error includes the above-mentioned laboratory calibration error and microphone placement error, as well as the error due to the use of an averaged directivity factor and the uncertainties associated with the dual channel FFT analysis applied.
- Long term environmental and aging drifts error may be taken at first from published work: Electret and MEMS microphones showed a negative correlation between sound level and temperature with a global error around 1 dB [6], while the variability from different phones of the same model was determined as negligible [7].

4.2. Discussion about the evaluation of uncertainties

The determination of these main individual uncertainty components aims to evaluate a practical value of the instrumentation error for the overall measured noise level. In ISO 9612 [4], the standard uncertainties associated with the instrumentation and the measurement position are defined for standardized instrument and are based on empirical data. These empirical data must be used, since the tolerance limits given in IEC 1252 [8] would lead to an overestimation of the instrumentation uncertainties [4]. The practical approaches for the assessment of each of these uncertainty components are still to be developed and preferably using "hands-on" approaches as in [5] and [9] for the specific constrains of the proposed use of smartphone-based instruments. For example, based on the evaluation tests defined in IEC 1252 as reference, the sinusoidal signals source should be modified for more "real world" industry noises.

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