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SMARTMEASURE

CiAUD Centro de Investigação em Arquitetura, Urbanismo e Design

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SMARTphone-based light and sound MEASUREment reliability

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Collaborating Researchers of CIAUD
Not applicable

External Researchers
MSc student

Keywords
Mobile phone | Accuracy | Illuminance | Noise | Monitoring

Partner Institutions
Not applicable

Expected Future Partner Institutions
- Ergonomics & Human Factors Group, ALGORITMi Research Center, University of Minho, Portugal
- Instrumentation & Applied Acoustics Research Group, Polytechnical University of Madrid, Spain

OBJECTIVES

Over the last few years, smartphones have become the main computing tool for most people, making them the ideal instrument in many areas and for many purposes. This project aims at identifying the main factors influencing the response of smartphones used to monitor light and noise and quantifying their impact. As a result, relevant information will be available for smartphone and app developers to improve technology and guidelines will be produced for OHS practitioners and workers on the most adequate set of smartphone/app to be used in order to produce a reliable noise and lighting diagnosis and choose the most suitable control measures. The objectives were set to achieve the aforementioned goals and include :

- comparing smartphones' reliability, when measuring light and sound, against that of light and sound meters;
- investigating if paid sound and light measuring applications improve smartphones' reliability in comparison to the non-paid ones;
- testing internal and external sensors' influence on smartphone performance as a light and sound measurement instrument;
- examining the effect of using different light and sound sources on the smartphones' output.

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ABSTRACT + IMAGES

Despite being two key and valuable environmental factors for workers to accomplish their job tasks, light and sound may turn into risk factors in occupational settings. Therefore, it is of paramount relevance to monitor and control these parameters to warrant the workers' health and safety and optimize their performance. Measuring noise and light in workplaces is regulated by national legislation and international standards which require compliant instruments for the task, such as light meters and sound level meters. However, this dedicated equipment cannot be supported by most SMEs for being costly and demanding training, maintenance and regular calibration by certified laboratories. Consequently, risks may not be assessed nor controlled, impairing the workers' health and safety.

Nowadays, mobile phones have high computational capabilities allowing real-time signal capture and analysis, which makes them a desirable multipurpose tool, namely for monitoring occupational risk factors. According to Statista's forecast, the number of smartphone users will reach 4.3 billion by 2023, meaning that an app running on a smartphone equipped with a microphone and a light sensor could turn the device into an adequate sound or light level meter and put professional measurement capabilities in the hands of millions of workers. In fact, there is growing interest in the use of smartphone-based applications (apps) as an alternative to monitor sound and light (Green et al., 2017; Iulietto et al., 2018; Odenwald, 2020). However, the main issue with using smartphones and sound and light measurement apps to date is that none comply with international sound and light meter standards. Therefore, they cannot be relied on to make regulatory-accepted occupational noise and light exposure assessments. This project aims to address this issue based on the research team's experience with noise and light monitoring with dedicated professional equipment and previous experimental research done with smartphones relying exclusively on free apps and built-in sensors (Cerqueira et al., 2018; Melo et al., 2020). Smartphones' reliability as light and sound measurement devices will be assessed and respective control factors will be investigated in order to acquire knowledge useful for improving this technology (Figure 1).

This project is crucial for Ergonomics and Occupational Health and Safety (OHS) because reliability of measurement instruments is required for sustained decision-making, particularly when people are at risk. It will also promote productive employment and fair working conditions for all, by ensuring healthy, safe and well-adapted work environments in accordance with both the 8th Sustainable Development goal of the 2030 Agenda and the 10th principle of the European Pillar of Social Rights. Moreover, smartphones have potential to drastically increase the number of measurements available for risk assessments and the general awareness of noise and light as a health hazards so that workers and employees can take steps to mitigate their negative effects.

A team including a full-time dedicated MSc student for 5 months and four researchers of CIAUD will accomplish a set of four tasks for a period of 12 months. Existing equipment includes a digital luxmeter from EXTECH Instruments, model LT45, and a class I Brüel & Kjær Sound Level Meter, type 2260 Investigator, to provide gold standard measurements. Additionally, a Pioneer X-HM21-K CD/USB receiver system equipped and a pair of 15 W speakers are also available.

University students and staff will be asked to volunteer their smartphones and a set of apps will be chosen based on established criteria and downloaded from app stores. These will be thoroughly tested against specialized instruments in a controlled environment, considering the following variables: smartphone models, paid/non-paid apps, illuminance and sound pressure levels, types of sound and light, light color temperature, and internal/external sensors (Figures 2 and 3).

Data analysis will be performed with IBM SPPS Statistics, including computation of descriptive statistics and the agreement level assessment between smartphone and professional instruments' performance with differentiated approaches, namely using Krippendorff's Alpha and linear regression analysis.

The obtained results are mainly directed for three different groups of people: smartphone manufacturers, apps developers and Ergonomics and OHS practitioners. The first two as technology producers and the last ones as technology users. Therefore, two paths for dissemination will be followed: a participation in an international conference within the ergonomics and occupational health and safety domains is foreseen, as well as the publication of an article in a peer-reviewed journal either in the ergonomics or the instrumentation fields.

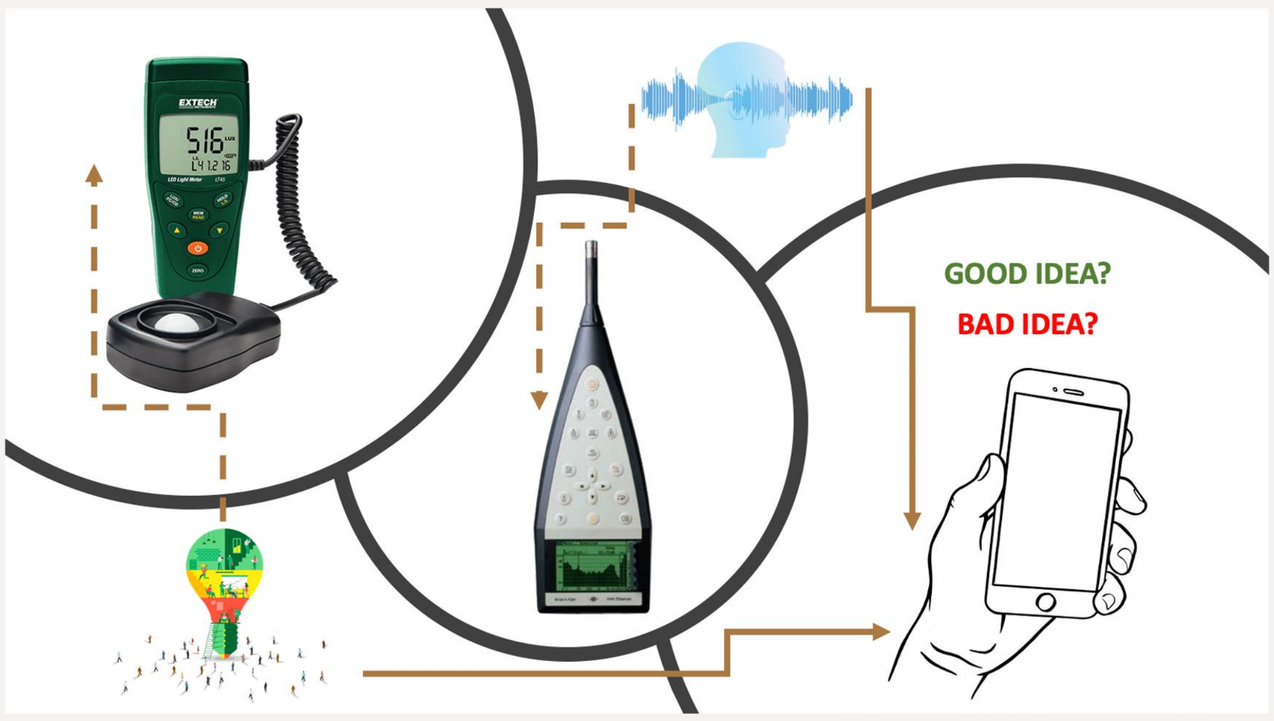

Figure 1 – Project's approach.

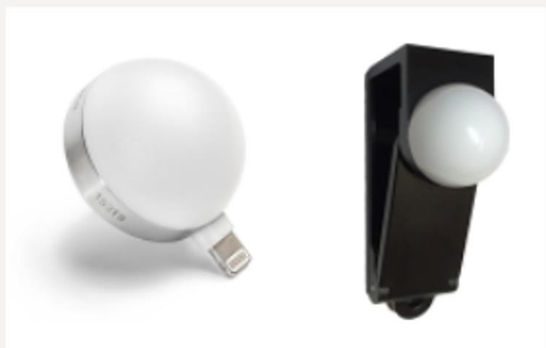

Figure 2 – External light sensors.

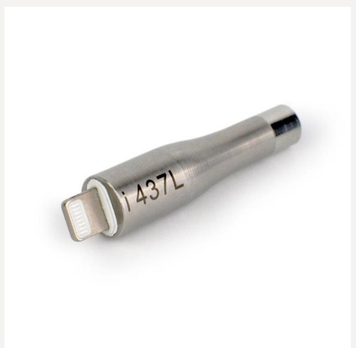

Figure 3 – External microphone.

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SCIENTIFIC RELEVANCE FOR THE DISCIPLINE

Noise and light measurements are required to acquire reliable information for effectively supporting decision-making processes within Ergonomics and OHS domains. A measurement system, comprised of measurement instruments and procedures, is the minimum requirement for performing measurements and obtain reliable results. However, the quality of results collected by smartphone-based apps is questionable since neither the apps nor the smartphones are considered to be compliant with international standards nor OHS regulations concerning sound and light measurement instruments. Accuracy assessments are necessary along with the identification of the controlling factors and quantification of their effects to provide valuable information for app developers (software for signal processing) and smartphone manufacturers (hardware: sensors) to improve technology and offer instruments with lower associated error.

EXPECTED ECONOMIC AND SOCIAL IMPACT

Monitoring occupational noise exposure and lighting have traditionally been conducted by research or academic institutions and external OHS service providers. It relies on dedicated measurement instruments, requiring training, regular maintenance and metrological checks, which can be expensive, particularly for SMEs. These factors may pose a barrier to employers conducting risk assessments. The use of emergent and more versatile technologies, such as smartphones, to monitor and thereafter control workplace lighting and noise will ensure not only safe conditions but also enhance productivity. A participatory approach, in which each worker can perform geo-localized measurements and send them to a server where post-processing is performed, enables producing noise and lighting maps and send back to him information on his exposure and how to behave. This methodology is aligned with the 8th Sustainable Development goal of the 2030 Agenda and follows the 10th principle of the European Pillar of Social Rights as it promotes productive employment and fair working conditions for all, by ensuring healthy, safe and well-adapted work environments.

RESEARCH PLAN AND TASKS

The project will take 12 months to be fully executed.

All experimental trials will be conducted in the Ergonomics laboratory, Faculty of Human Kinetics, University of Lisbon, under controlled sound and lighting conditions.

A Master student will be fully dedicated to this project and four researchers of CIAUD will assist him while having a more active role during data processing and the preparation of the conference presentation and writing an article to be published in a peer reviewed journal.

A more detailed and up-to-date literature review will be conducted to support the experimental set-up options and the results discussion. A survey on the most acquired/used smartphone models will be made so that the sampled equipment be representative. This will also be done for smartphone-based applications in order to choose the most suitable to measure light and sound and not spend time with those already tested and proved no to be reliable. Based on a preliminary literature review and the team's experience from previous studies with smartphones (Cerqueira et al., 2018; Melo et al., 2020) the following independent variables will be considered for testing: smartphone models, paid/non-paid apps, illuminance and sound pressure levels, types of sound and light, light color temperature, and internal/external sensors. As far as possible, confounding factors will be controlled. Prior to any testing session involving volunteers, the selected apps will be tested on one of the team members' smartphone. In order to optimize their participation, tasks 2 and 3 will take place sequentially for each smartphone.

Task 1: Experimental trials' preparation

Recently developed smartphone applications to acquire acoustic and lighting data will be searched on app stores and on the Internet, after analyzing previous studies and based on predefined criteria. Among these are the ability to report measurements instantaneously and as numerical values as requested by international standards and legal regulation on occupational noise and lighting (Equivalent continuous A-weighted sound pressure level - LAeq, C-weighted sound pressure peak level - LCpeak and illuminance, expressed in lux), number of downloads, users' ratings, positive reviews and in-app calibration offer. Representative sound signals will be chosen from a sound library, ensuring that they can be reproduced at different pressure levels. A set of light bulbs will be elected in order to provide illuminance levels within the range recommended for workplaces by international standards and covering the three main classes of color temperature (warm, natural and cool white). University students and staff will be requested to volunteer their mobiles phones to be tested. They will be informed about the project objectives and the tests their smartphones will be subjected to so that they can provide free, informed and written consent for us to use their equipment and the experiment may be scheduled. The project complies with international ethical standards. All volunteered equipment will be noted for condition, age and installed operative system version because these may interfere with their measuring performance and prevent the apps installation. According to national legal regulation, the Sound Level Meter calibration by a certified laboratory is mandatory.

This task will take about 1.5 months to be concluded by RBM and FC.

Task 2: Assessment of smartphone reliability as a light meter

Once the volunteer arrives at the Lab, the selected apps must be installed on his smartphone and the calibration process completed. All tests will be performed in a black chamber with no natural light admission, a light sealed door and black painted walls. These conditions will ensure that the exact same light will be used in all tests and light reflections are reduced to a minimum. Moreover, the experimenters positioning will be carefully controlled so that their shadows do not fall either on the lux meter sensor nor on the smartphone camera. A digital luxmeter from EXTECH Instruments, model LT45, with a ±3% accuracy level will be used to provide gold standard values. Measurements will be recorded for each app (paid and non-paid) on each smartphone, with its front camera and two external sensors (Figure 2), at each illuminance level (within the range recommended by international standards for occupational settings) for each light bulb type and each color temperature. For each test, the lux meter photoelectric cell and the front camera of the device will be sequentially aligned directly below each light bulb for measurement. Different illuminance levels will be simulated either adjusting the distance between the light bulb and the platform where the instruments will be placed or using a dimmer. This task requires purchasing light bulbs which will be used as light sources, batteries for the lux meter and two external light sensors. The MSc student will be responsible for most of the experimental work and will be assisted by RBM and FC.

A period of 3 months is forecast for this task.

Task 3: Assessment of smartphone reliability as a sound meter

The process begins with the installation of the selected apps on the volunteer's smartphone, followed by its calibration. Background noise will be measured to ensure it is low enough and does not interfere with the calibration process nor with measurements. This will be accomplished with a class I Brüel & Kjær (B&K) Sound Level Meter (SLM) type 2260 Investigator which will be calibrated before each testing session with a B&K calibrator, type 4231. The sound signals will be cut and looped to deliver consistent sounds for all measurements and played with a Pioneer X-HM21-K CD/USB receiver system connected to a pair of 15 W speakers. The SLM and each smartphone will be positioned 1 m from the floor and 1 m in front of the speakers with their microphones oriented towards them. The researchers will be silent and behind the measurement instruments during tests not to interfere with played sound. Signals will be generated with predefined and constant increments between 60 and 90 dB to be representative of the noise levels most common workers are subjected to. Measurements will be recorded for each app (paid and non-paid) on each smartphone, with both the internal and the external microphone (Figure 3), at each sound level within the 60-90 dB range, and for all sound signals. LAeq, LCpeak and Octave 1/1 spectra will be registered and compared to the SLM output. The MSc student will be responsible for most of the experimental tasks and will be assisted by RBM and FC. This task involves acquiring sound signals from a sound library, batteries for the SLM and one external microphone.

It is predicted that this task will take 3 months to be completed.

Task 4: Data processing and preparation of dissemination

Statistical analysis of data will rely on IBM SPSS Statistics® (version 27) and will involve the 4 researchers of CIAUD more actively. Descriptive statistics will be computed by smartphone model, by app, by sensor type and by the signals' characteristics. An innovative and unusual approach is foreseen by using Krippendorff's Alpha coefficient to assess the agreement level between smartphone and professional instruments results. A presentation will be prepared for the annual Applied Human Factors and Ergonomics conference along with an article to be submitted for publication in one of the following journals: Applied Ergonomics, Measurement or Sensors. Eventually, an article processing fee will have to be paid.

This task will have a maximum execution period of 2.5 months.

EXPECTED SCIENTIFIC RESULTS

An Ergonomics MSc student will write and discuss his thesis based on this research study. Relevant information will be produced for both smartphone manufacturers and application developers to improve technology to be used within the Ergonomics and OHS domains. Despite being equipped with a variety of sensors (hardware) and the multiplicity of available applications (software), smartphones still present some flaws as measurement instruments and potential users must be aware. Guidelines concerning best smartphone/app pairs to be used either for sound or light measurements and operative conditions will be produced. In order to accomplish dissemination of the results, a presentation at the annual Applied Human Factors and Ergonomics Conference is foreseen as it is one of the largest and most relevant within the area and includes attendees from the academia and the industry, namely ergonomists and OHS managers. Moreover, an article is due to be submitted for publication on Applied Ergonomics, Measurement or Sensors which are Q1 peer reviewed journals in the fields of ergonomics, measurement and instrumentation science and technology with a vast audience.

BUDGET: € 7.430,60

Funding in a total of € 7430,60 is requested for:
Human resources: a 5-month research scholarship for a full time MSc student to execute most of the experimental work (€ 2230,60);
Missions: Applied Human Factors and Ergonomics Conference registration fee and intercontinental plane ticket to disseminate the obtained results (€ 1700,00);
Acquisition of other goods and services: Metrologic verification of the sound level meter by a certified laboratory as required by legal regulation (€ 400,00);
Demonstration, Promotion and Dissemination of the Project Results: article processing charge making it free for readers which enables reaching a larger community of professionals (€ 2000,00);
Other current expenses: batteries for the light and sound meters, light bulbs, sound signals download from online library and download of paid apps (€ 600,00);
Equipment: external microphone, external wired and non-wired light sensors (€ 500,00).