Hand-Arm Vibration Estimation Using A Commercial Smartwatch

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Abstract

Measuring Hand-Arm Vibration (HAV) exposure is important to prevent permanent injuries, such as the White Finger / Raynaud Syndrome. Current measuring solutions require an individual attachment of those work tools that emit considerable vibrations. These sensing instruments are expensive and usually require a setup by experts. Additionally, these attached sensors are bulky and wired, which may further increase the risk of accidents in occupational safety. For an easy use, we propose using a Smartwatch to estimate the HAV doses gathered throughout the day. By utilizing the Smartwatch's Inertial Measuring Unit (IMU) that is sampling up to 800Hz, we are capable of reconstructing vibrations up to 400Hz. This range sufficiently covers the majority of harmful HAV loads that occurs with work tools. Our approach is an inexpensive solution that provides a rough estimation to indicate a vibration overload. Our solution does not require the specific tool type or datasheet.

Keywords:

Hand-Arm Vibration Estimation; Smartwatch; Sensing; Accelerometer; HAV Exposure Dose.

Introduction

There have been many research investigations looking into understanding the risks of injury from hand-transmitted vibration and whole-body vibration by means of epidemiological studies [1]. The most crucial impact is the Raynaud Syndrome [3], which is a vascular spasm that negatively affects vessel blood flow. This can be caused when exposed to cold or stress, such as operating work tools that emit considerable vibrations [4] to the hand and arm. Vibrotactile perception in the fingertips can become numb on a short-term temporal or long-term basis [6].

When the human body to the exposure to vibrations without limits, symptoms such as coldness of the hands, the legs, hypesthesia of the fingers, tremor/shivering of the fingers, dexterity disturbance, weakness of the hands, mobility disturbance of the elbow, shoulder/neck stiffness, low back pain, fatigue, headache, dizziness, tinnitus, and hearing loss can occur. These symptoms have been evident among quarry workers in developing countries such as Vietnam [7], where occupational safety is not highly practiced.

Different methods and technologies based on measuring Hand-Arm Vibration [5], such as using high-sensitive accelerometers [8], are used to prevent such symptoms. These dosimeters are precise and provide sampling rates up to 5kHz. Since these technologies are usually expensive and instrumenting work tools with additional sensors may create an increased risk in occupational safety, using wearable technology such as a Smartwatch is a logical step. IMUs, in particular Accelerometers and Gyroscopes, that are implemented in Smartwatches so far only enabled sampling rates of up to 100Hz without kernel modifications. Determining an accurate HAV is insufficient with this sampling rate, since emitted vibrations can exist beyond this frequency. Research explored a work-around when attempting to measure HAV exposure doses with Smartwatches [2], such as using the accelerometer in conjunction with the microphone to identify the tool the worker used. Once the tool is known, it's specific HAV ratio is being looked up from a database. However, this requires the system to have access to a complete database with all HAV ratios from a great variety of work tools.

Method

In this paper, we propose an alternative approach, in which we use the IMU of a commercial Smartwatch to calculate a rough estimation of the HAV received at the user's wrist. This way, measuring the exact HAV exposure doses is not possible because of the signal absorption, signal coupling, and transmission loss between the vibration emitter (tool) and wrist (Smartwatch IMU).

In fact, the current Android Wear OS (2.9 – based on Android 8.0.0) provides a new direct channel to assess the acceleration sensor. Apparently, new devices will be able to sample the IMU with a frequency up to 800Hz. Following the Nyquist–Shannon sampling theorem, frequencies of 400Hz can be reconstructed accordingly. Although, this may still appear too low to sense the full spectrum of the vibration exposure, it enables us to read most critical root-mean-square (r.m.s.) acceleration magnitude - represented as a frequency weighting curve W_h *(see Figure 1)*.

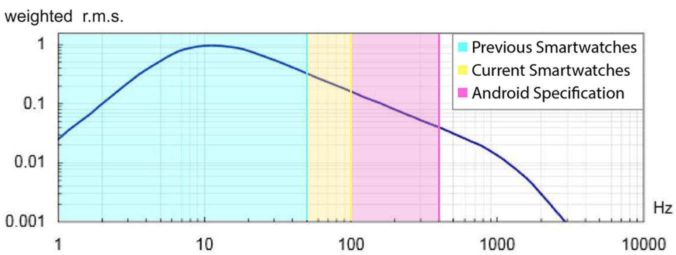

Figure 1. Hand-arm vibration frequency weighting curve W_h following ISO 5349-1:2001 [9]. The highlighted areas shows the coverable frequencies.

Therefore, our hypothesis is that a commercial Smartwatch is sensitive enough to provide an acceptable approximation of the actual HAV exposure doses.

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Preliminary Field Study

We developed a smartwatch app running on an autarkic Android Smartwatch. We used the model Simvalley AW420-RX running Android 4.2. The watch has a Cortex A7, 1 GB RAM and incorporates a Bosch BMC050 IMU, which quantizes +/- 2 g (19,62m/s2) with 12bit. The weight of the watch is approximately 90 grams.

Figure 2. We ran a preliminary field study in metalworking / manufacturing. The participants were equipped with a smartwatch running our app, as well as with a microphone and a GoPRO to measure the ground truth data.

We selected a window size of 128 samples of acceleration tuples while using 50Hz. We assume that any harmful HAV occur between 0–25Hz, which can be measured by the Smartwatch. We calculated the significant acceleration of the Smartwatch within the 3D-area by this formula:

$$a_{3D} = \sqrt{(x-\bar{x})^2 + (y-\bar{y})^2 + (z-\bar{z})^2}$$

Our assumption concludes that tools with a slow motor and slow motions would also lead to a low acceleration.

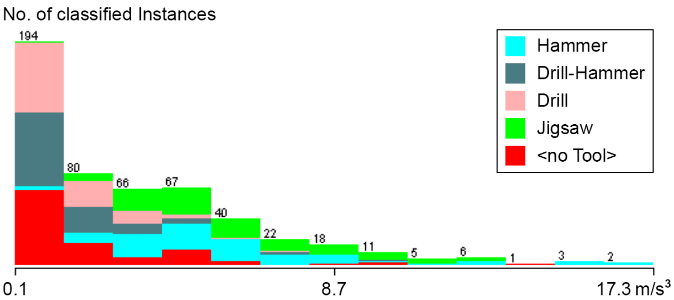

Figure 3. Distribution of measured 3D-acceleration (jerk) measured at the wrist.

It becomes clear by Figure 3 that not only emitted tool vibration is sensed, but also any other motion the worker performs in the workshop. Therefore, we suggest classifying typical motions that occur with <no Tool> and to subtract this from the daily exposure doses.

In our preliminary field study, we used a low sampling rate that is only capable of reading limited vibrations. For future research, we suggest utilizing Smartwatches with high sampling rates to capture a wider spectrum.

Moreover, we found that the measured 3D-acceleration force does not directly correlate to the HAV. We believe this is mainly due to the non-linear absorption of the vibration frequencies at the fingers, the hand, and the wrist. Also, we noticed that the wristband's tightness to have a significant influence on sensing the 3D-acceleration force.

Taking these factors into account, we believe reproducing the correct HAV exposure doses could be possible.

Discussion

As demonstrated in Figure 1, the most harmful HAV occurs in the lower frequency spectrum between 2.5–50Hz. Capturing these should be prioritised. While professional sensing tools are usually expensive and impractical, we propose using a Smartwatch to estimate these. However, an exact measurement is not possible due to various parameters such as the contact pressure between hand and tool, signal absorption by the joints, tightness of the wristband, etc. Aside from these factors, smartwatches are becoming increasingly powerful. They can provide a greater sampling rate and are capable of sensing an increased range of the frequency load. Nevertheless, a professional measurement equipment is still superior. The proposed work-around in AGIS [2] may still be the state-of-the-art when measuring a more accurate HAV with unmodified Smartwatches. In fact, the advance of the increased sampling rate with Smartwatches can also benefit a greater tool detection. Sampling the IMU with 800Hz may provide enough signal characteristics to identify tools based on the accelerometer only. Once the tool is identified, looking up the HAV intensity ratio from the datasheet for each tool would still be next step to calculate the daily dose. We see Smartwatches as the gatekeeper for calculating the exposure duration of harmful vibrations. In the future, we envision smart wearables to enter different industry branches, provided that the legislator paves the way. Furthermore, we see this technology as being capable of registering the exposures in a cadaster, namely to distinguish between regional and branch specific workloads.

Conclusion

The advancements in IMU sensing enables an estimation of HAV exposure with commercial Smartwatches. Still, an accurate measurement is yet problematic. In particular, we are required to account for the non-linear absorption of vibration frequencies into the hand and the tightness of the wristband. Calculating the exact HAV dose using a Smartwatch is feasible when running a tool detection, but which requires a large database and thus is impractical.

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