**Automated Hand-Arm Vibration Monitoring of Construction Worker Using Smartwatch and Machine Learning**

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## Abstract

Hand-arm vibration (HAV) can be defined as the transfer of vibration from a tool to worker's hand and arm, and the adverse effect of HAV are defined as hand-arm vibration syndrome (HAVS). Workers in construction industry often work with hand powered tools with generates vibrations and prolonged exposure to such vibrations causes disorders related to vascular, neural, and musculoskeletal system. By reviewing 20 cross sectional studies in 1997, National Institute of Occupational Safety and Health (NIOSH) found a positive correlation between high level of HAV and HAVS. Although, there are several regulations, and guidelines to limit the HAV exposure of workers, the current method of measuring HAV exposure requires high investment (i.e., expensive equipment), as well as significant manual effort. Moreover, companies just test their equipment periodically to check if the vibration of the equipment is within the limit of the regulation. However, the HAV exposure depends a lot of other factors, such as hours of use, grip force, posture, rest break etc. Thus a low-cost, automated and continuous HAV exposure monitoring system can significantly lower the risks of HAVS among construction worker. This project tests the feasibility smartwatches to automatically monitor real-time HAV, by utilizing the accelerometer embedded in the smartwatches and machine learning algorithms. Vibration data was collected from various hand-powered tools wearing a wearable accelerometer. Then, the raw accelerations was used to recognize what type of equipment is in operation. Finally, using previous knowledge on HAV exposure levels of different equipment, real-time HAV exposure was predicted. The result of this study shows promising potential of such system to be adopted in real-life construction operations in order to continuously monitor and control the HAV exposure of the worker.

## Background

An estimated 1.45 million workers use vibrating tools in the United States [1]. In a worker population that has used vibrating tools, the prevalence of HAVS ranges from 6% to 100%, with an average of about 50% [2]. According to the Medical Research Council survey, it was found out that nearly 5 million people are exposed to hand transmitted vibration during a working weeks [3]. The majority of the people affected by this are men, with a male to female ratio of approximately 8:1. Also, The US National Institute for Health performed a study and found a strong inter-relation between HAV and human health [4]. These studies were focused on a group of workers who deal with HAV in day to day life, for example, carpenters, stone drillers, forestry workers [4]. From this study, it was concluded that more the frequency of vibration and duration of exposure greater it would have an impact on the worker those who are handling the equipment. Usually, minimum daily exposures for several hours each day for month or years are usually required before the first signs of symptoms appear.

There are two types of vibrations experienced by the person who is in contact with a vibrating machinery or is participation in such an operation. The first type is whole-body vibration which occurs when the human body is standing or is supported by the vibrating surface. The second type is the hand-transmitted vibration which occurs when the vibration is transmitted to the person's body through the hands. Hand-arm vibration is vibration transferred from a hand-held power tools, hand-guided power machinery to a person's hand and arm. These mechanical vibrations emanate from different processes and operations prevalent across variety of sectors such as construction, forestry and agriculture [5]. Figure 1 shows the distinction between the two.

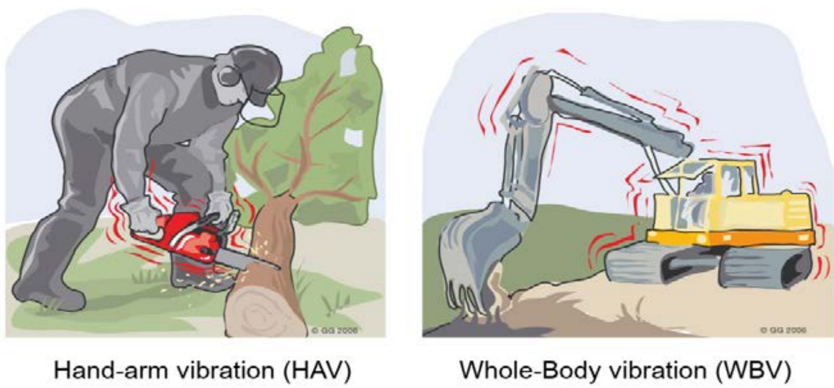


Figure 1: Different types of vibrations experienced by workers [6]

Workers in construction industry often work with hand powered tools with generates vibrations and prolonged exposure to such vibrations causes disorders related to vascular, neural, and musculoskeletal system. Vibration exposure has been identified as a serious health risk and has been known as the cause of what is known as Hand-Arm Vibration Syndrome (HAVS) [7]. The symptoms include episodic numbness; tingling and blanching of the fingers, with pain in response to cold exposure; and reduction in grip strength and finger dexterity [8]. These signs and symptoms are known to increase in severity as exposure to vibration increases in intensity and duration [9]. By reviewing 20 cross sectional studies in 1997, National Institute of Occupational Safety and Health (NIOSH) found a positive correlation between high level of HAV and HAVS [9]. The severity and the time of onset of HAVS is highly correlated to the 'acceleration exposure dose' which is the product of acceleration level and exposure duration. Therefore, it becomes imperative to measure these parameters and bring them down to safe levels.

**Current practice in measuring HAV exposure**

To prevent HAVS and other health risks associated with HAV, vibration exposure limits have been recommended through EU directives and ISO 5349-1 and -2 guidelines [10]. In these documents, the methodology to calculate the daily exposure value has also been specified. The key terms used in these standards are explained below:

- Daily vibration exposure A(8): the quantity of HAV a worker is exposed to during a working day, normalized to an eight hour reference period, which takes account of the magnitude and duration of vibration. Daily vibration exposure is derived from the magnitude of the vibration (vibration total value) and the daily exposure duration.

- Exposure action value (EAV) means the level of daily vibration exposure to HAV for a worker above which steps should be taken to minimize exposure.
- Exposure limit value (ELV) means the level of daily vibration exposure to HAV for a worker which should not be exceeded

Table 1 shows the limits of EAV and ELV established by the European Union.

Table 1: EU Directive limits for EAV and ELV [10]

| S. No. | Parameter | Limit |
|---|---|---|
| 1. | Exposure action value (EAV) | 2.5 $m/s^2$ |
| 2. | Exposure limit value (ELV) | 5.0 $m/s^2$ |

As per ISO standards, the evaluation of vibration exposure utilizes a quantity called vibration total value ($a_{hv}$) which is defined by equation (1).

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad \text{Eq. (1)}$$

Where,

$a_{hwx}$, $a_{hwy}$, $a_{hwz}$ are the frequency weighted acceleration values in the x, y and z directions.

Figure 2 shows the measurement axes for HAV along which the accelerations are experienced by a worker:

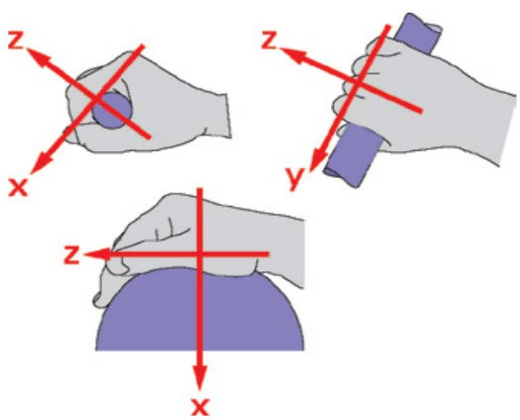


Figure 2: Measurement axes for HAV. [11]

This value of $a_{hv}$ is used to obtain the daily vibration exposure by equation (2).

$$\text{Daily vibration exposure, } A(8) = a_{hv}\sqrt{\frac{T}{8}} \qquad \text{Eq. (2)}$$

Where,

A(8) = 8 hour equivalent acceleration ($m/s^2$)
T = actual exposure duration in hours

If the A(8) as obtained above exceeds the ELV 5.0 m/s$^2$ then the employers must evaluate the necessity of decreasing worker's vibration exposure. The employers should also take action of decreasing the vibration exposure even when A(8) obtained exceeds EAV 2.5 m/s$^2$.

### Research gaps and goal of this project

Generally, vibration exposure is not measured continuously and not recorded systematically. The measurements are mostly carried out in frequently. The calculation of exposure is done from the qualification values for vibrating equipment and the exposure time which is roughly estimated. The current method of measuring HAV exposure requires high investment (i.e., expensive equipment), as well as significant manual effort. Moreover, companies just test their equipment periodically to check if the vibration of the equipment is within the limit of the regulation. However, the HAV exposure depends a lot of other factors, such as hours of use, grip force, posture, rest break etc. Thus, a low-cost, automated and continuous HAV exposure monitoring system can significantly lower the risks of HAVS among construction worker. This project tests the feasibility smartwatches to automatically monitor real-time HAV, by utilizing the accelerometer embedded in the smartwatches.

### Methodology

The overall framework proposed in this project is shown in Figure 1. Real-time vibration data will be collected from the worker wearing a smartwatch. The vibration data will be used to predict what type of equipment s/he is operating. Then duration of each equipment usage will be calculated from the timestamps recorded. Previous studies or the domain knowledge will be integrated with the duration to predict the HAV exposure. Finally, if the worker reach to the daily HAV limit, a mobile alert will be sent to take necessary action. This project specifically focuses on the data collection and prediction part as shown in dotted box in Figure 3.

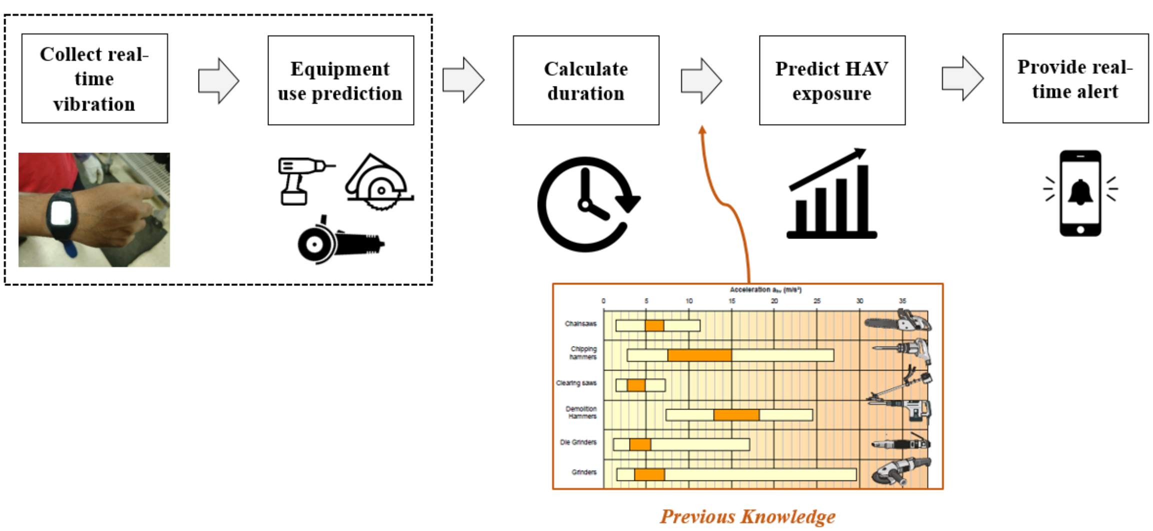


Figure 3. Overall framework of the project

Figure 4 illustrates the four major steps undertaken to accomplish the goal of this study. Initially data are collected from worker wearing a wearable inertial measurement unit (IMU). The IMU device contains an accelerometer, a gyroscope and a magnetometer. For this particular study only accelerometer is utilized which captures the vibration of the hand. Vibration data are then processed, segmented and necessary feature vectors are extracted to train the model. Nine time-domain features are extracted from each segment in this study. They are mean, median, maximum, minimum, interquartile range, standard deviation, skewness, and mean absolute deviation. A support vector machine (SVM) is trained using the features. Finally, the trained model is used to predict which equipment the worker is using.

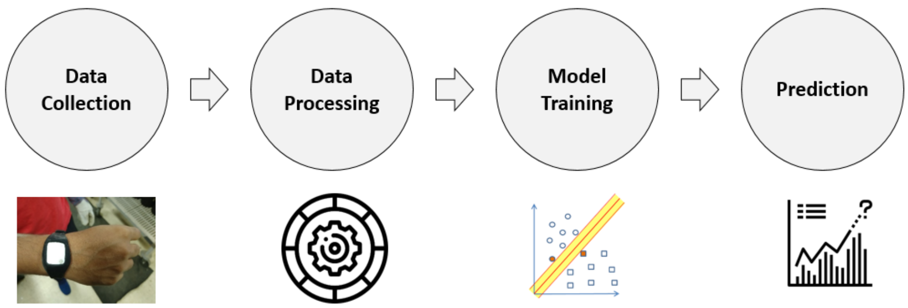


Figure 4. Steps involved in the project

**Experiment and result**

In order to validate the proposed methodology, data were collected from three different types of equipment; electric drill machine, table saw, and hammer. One student volunteered with the drill machine and hammer. And data from an actual worker was collected using a table saw. For each equipment, approximately two minutes worth of data were collected. The collection is process is shown in Figure 5 (left). Figure 5 (right) also visualizes the 3-axis vibration data collected from three equipment.

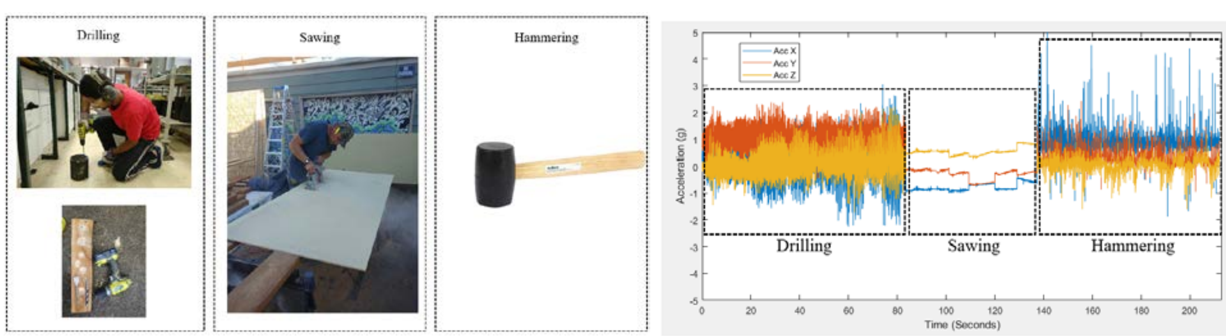


Figure 5. Data collection and visualization

The vibration data shown in Figure 5 (right) are used for segmentation and feature extraction. An SVM model was trained using the features. 5-fold cross validation approach was implemented to validate the proposed methodology. Figure 6 shows performance measures of the model. Accuracy, precision, recall, F-1 score, and confusion matrix were used as performance matrices. The model provides almost 100% accuracy for all four performance measures. Also, the confusion matrix demonstrates good fidelity of the model. However, due to the limited volume of training data, the model probably over-fitted, and that caused the unusual good prediction results.

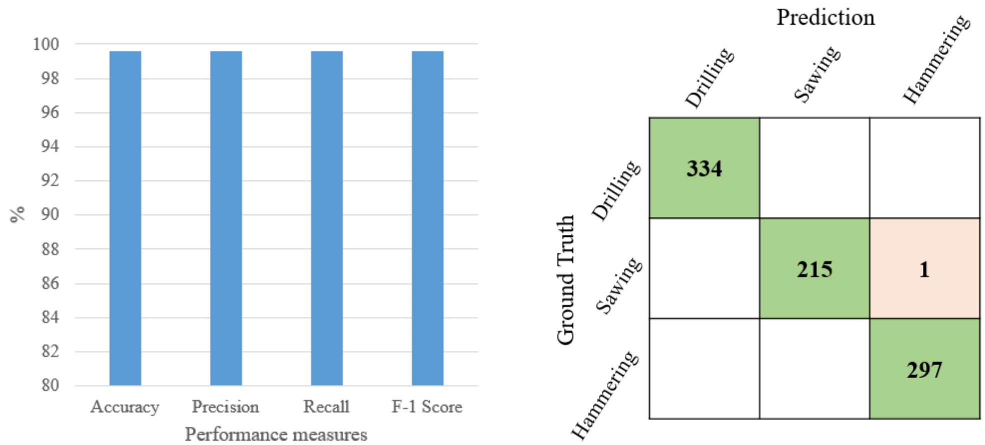


Figure 6. Performance measures of the analysis

## Discussion

Despite low amount of training data, and unusually good results, this study demonstrates the feasibility of using smartwatches to predict what type of equipment the worker is operating. From this, the duration of each equipment use can be calculated. This durations can be further integrated with previous knowledge to calculate the HAV exposure of the worker. The fitness tracking tracking systems available in the marker take a similar approach while calcualting the calory burn. Figure 7 depicts the similarity between the fitness tracking technologies available in the market and our proposed methodology. As the proposed approach is very similar to already used hardwares (i.e., smartwatches), there will be no added cost in that aspect. Also, this methodology does not require any change in work perception and worker training.

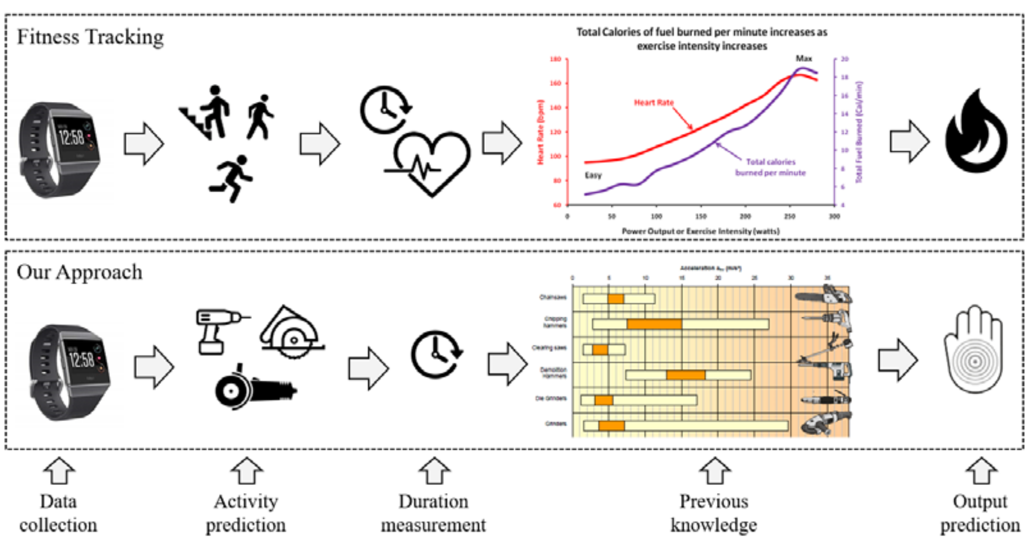


Figure 7. Similarity between proposed approach and fitness tracking technology available in the market

## Conclusion and future work

The purpose of this study was to explore the possibility of use of smartwatches to automatically monitor real-time HAV, by utilizing the accelerometer embedded in the smartwatches. A preliminary test carried out on three different equipment yielded positive results. The proposed method of measuring vibration exposure is not only real time, it is also quite practical and low cost and very similar to the devices already popular in the market. However, before implementation of an actual site the model should be tested and calibrated with more equipment in different settings. The future work of this study includes testing the framework with wide variety of equipment, and with larger data set. Moreover, a smartphone-based alert system can be integrated with this method to provide real-time alert to the workers, as well as to the managers to monitor the HAV exposure, and prevent excess exposure to the HAV, reducing the risk of HAV related health issues.

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