A wearable low-cost device for measurement of human exposure to transmitted vibration on motorcycle

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Abstract — **The comfort experienced driving a motorcycle is becoming a subject of great importance, indeed, the driver is exposed to vibrations, which in some cases may cause troublesome problems. The vibrations, during the driving of a motorcycles, are caused by irregular profiles of the road surface or by the wear of the latter; these conditions, unfortunately, are present in almost all the driving conditions, reason why each driver is exposed to it. The aim of the paper is to give the opportunity for the driver to know the exposure to the vibration during a ride using a low-cost wearable device (smart watch) considering the suggestion of the ISO 5349 for the calculation of the hand transmitted vibrations index. A suitable measurement system has been designed and tested on a real motorcycle in order to acquire in real-time the acceleration signals through a Bluetooth communication, which interface a wearable device with a microcontroller unit useful to calculate the hand transmitted vibrations index suggested by the ISO 5349 and store it into a data logger.**

Keywords—vibrations, wearable device, accelerometer, ISO- 5349, motorcycles.

I. INTRODUCTION

The transmission of vibrations from a vehicle to the human body has become a topic of great importance and it is at the center of many studies and researches aimed at identifying the problems related to human exposure to these stresses [1]. Vibration is defined as a variation of the magnitude value as a function of time describing the position and motion of a mechanical oscillatory system around a balancing point. Human exposure to vibrations has increased progressively with the development of agricultural, industrial mechanization and the use of vehicles.

Today the vehicles are used at least for one hour during a day, so it has become very important to analyze the phenomenon of vibrations caused by that types of stresses on the human body. As previously said, the mechanical vibrations are produced by the oscillatory movement of a body around a position of equilibrium, they are characterized by the frequency (Hz), the amplitude (m/s^2) and the time of exposure of the body to vibration.

Vibrations in many cases are effects not desired, that can disperse energy by creating sounds and noises, as in the case of vehicles and engines. The research in this field deals with various effects of vibrations on different parts of the human body that is a very complex phenomenon [2]. These studies consist in the analysis and control of all possible interferences of the vibrations with the human body causing discomfort and adversely affecting the activities and well-being of a person. Exposure for a short period of time of the human body to vibration causes small physiological effects such as the increase of the heart rate or the increase of muscular tension. On the other hand, exposure to vibration for a long period of time causes effects such as alteration of the spine, degenerative processes of lumbar segments such as deforming spondylosis, arthrosis, digestive system problems and issue with the genital and urinary system[2]-[3].

There are some international regulations that supervise the exposure of a human to different sources of vibration. The reference standards for the analysis of human exposure to vibrations are the ISO 2631-1 [4] and ISO 5349 [5]. The main purpose of the standards is to define methods to quantify the vibrations transmitted to the body in relation to the well-being and human health. The rules do not indicate actual limits of vibration exposure, but they define vibration assessment methods for exposure risk that can be used as a basis for determining these limits. We can distinguish the standards ISO 2631-1 and ISO 5349 for the type of vibration and the part of the human body of interest exposed to vibrations:

- ISO 2631-1 assesses exposure to whole body vibration, "whole-body Vibration" WBV
- ISO 5349 evaluates exposure to vibration transmitted to the upper limbs (hand-arm vibration system), "Hand Transmitted Vibration" HTV.

The vibrations transmitted to the whole body can cause feelings of uneasiness and discomfort, influencing human performance capacities or exposing the human body to a risk to safety and health, for example pathological damage or psychological changes. Vibrations can occur in different directions, contain many frequencies and vary over time. The standards establish the criteria for the measurement of periodic, random and transient vibrations transmitted to the body. Harmful effects on the human body can be caused by exposure to vibrations close to the resonance frequencies of the various parts of the body. For example, the spine has a resonance frequency of about 5 Hz which is also produced by many machines for earth- moving

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[6]. About the vehicles, motorcycles represent vehicle of huge interest for the vibration analysis due to the more sensibility, than other vehicles, to the road asperity [7]-[8].
The vibration analysis for a motorcycle ranges, in term of frequency, from 0.25 Hz to 20 Hz [9]-**Error! Reference source not found.**. More in details, the excitations at very low frequencies, below 0.25 Hz, are caused by the natural variations of the slope of the road and are not transmitted to the human body. The frequencies above 20 Hz and up to 20 kHz can be associated with noise, causing different sensations in humans during the driving but not caused by the vertical movement of the motorcycle. The remaining frequencies range, among 0.25 to 20Hz could, be also divided into other two range: frequencies lower than 1.5Hz that are generated can be neglected due to the low contribution in terms of vibration; frequencies from 1.5Hz to 20Hz that includes all the main vibration expected by the vertical dynamics of a motorcycle [10]-[11] . The most significant component for the exposure of the human body to the vibrations during a motorcycle ride is the vertical acceleration. In fact, the inertia forces to which the internal organs of the passenger body are subjected are proportional to the vertical acceleration, while their relative displacements are influenced by the frequency of excitation [13].
The aim of the paper is to experiment the use of wearable device, object that are today commonly used in the everyday life, to evaluate the vibration transmitted to a human body during a motorcycle ride.
The paper is organized as following: section II describes the measurement system used for the aim, section III reports the experimental results showing the HTV index calculated for different types of road.

II. The Measurement System

A typical urban motorcycle has been used for the evaluation of human body exposure to vibrations during a ride. A suitable data acquisition system has been set up including a wearable device worn by the driver and a data acquisition system able to sample the acceleration data measured on the arm of the driver. More in details, the measurement system (see Figure 1) is composed by:

- • Wearable device ST STEVAL-WESU1.
- • STM32F401RE Nucleo Board equipped with a Bluetooth module.

Figure 2. The reference system for the wearable device

- • Data logger MDLOG (SPRING OFF)

The wearable device STEVAL-WESU1 [14] is provided with MEMS accelerometric sensor for the measurement of accelerations in the ranges of ±2g/±4g/±8g/±16g. The measurement of the accelerations for the evaluation of the vibrations transmitted by the motorcycle to the driver should be carried out directly on the points of contact among the motorcycle and the driver but , in this work, it was decided, according to the use of a wearable device, to put the sensible device directly on the driver's arm.
The axis reference system of the accelerometer sensor according to the wearable device arrangement (located on the left wrist) is shown in Figure 2.
The STM32F401RE Nucleo board [15] is responsible of the data recording, carried out at the sampling frequency of 100 Hz, over a Bluetooth bridge with the wearable device. As for data logging, a suitable data acquisition system was designed for storing the data collected by the STM32F401RE Nucleo Board. The data acquired at a frequency of 100 Hz are:

- Acceleration value on the x-axis a_x
- Acceleration value on the y-axis a_y
- Acceleration value on the z-axis a_z

The experimental road tests were performed with the Piaggio Beverly 300 introduced above. Several tests have been carried out on a mixed urban-suburban road, specifically choose to obtain data on different road surfaces, collecting data for about

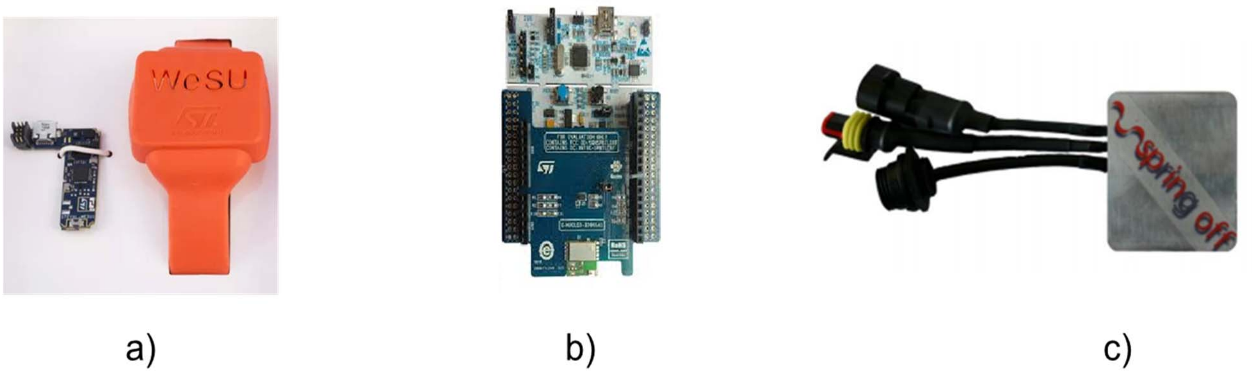

Figure 1. The measurement setup: a) The wearable device, b) The Nucleo board equipped with the Bluetooth module c) The data logger

Figure 3. The road experimented: a) Urban road with irregular profile, b) Cobblestones, c) Extra urban road, d) Highway

40 km. The roads experienced as reported in Figure 3, is so divided:

- 10 km of urban road with a not uniform road surface
- 10 km of cobblestone
- 10 km of suburban road
- 10km of highway

III. Experimental Results

The aim of the experimental test is the possibility to evaluate the vibrations to which the body is exposed during a motorcycle ride using a low-cost wearable device; to have a more accurate evaluation, tests have been carried out on different road surfaces. For the measurement of the vibrations generated by the motorcycle and transmitted through the handlebar, have been adopt the technique described in ISO 5349 which estimates the vibrations conducted to the hand-arm system (Hand Transmitted vibration HTV).

The vibration assessment described by the standards are based on the calculation of the mean quadratic acceleration (RMS) weighted in frequency, expressed in meters per second square, according to the following equation:

$$a_w = \sqrt{k_x^2 a_{w,x}^2 + k_y^2 a_{w,y}^2 + k_z^2 a_{w,z}^2} \qquad \text{Eq.(1)}$$

where $a_{w,x}$, $a_{w,y}$, $a_{w,z}$ are the mean quadratic acceleration (RMS) weighted in frequency of the different axes and k_x, k_y, k_z represent a multiplicative factor defined by the ISO 5349 that depend by the position of the subject and the contact point between the vibrating surface and the body. In our case those multiplicative factors are considered equal to 1 as it was neglected the influence of the subject with the contact point [16]. The values of the accelerations $a_{w,x}$, $a_{w,y}$, $a_{w,z}$ are calculated for each axis (x, y, and z) applying a suitable weighting factor according to (2).

$$a_{w,x} = \sqrt{\sum_i (W_{hi} a_{hi,x})^2} \quad a_{w,y} = \sqrt{\sum_i (W_{hi} a_{hi,y})^2} \,.$$

$$a_{w,z} = \sqrt{\sum_i (W_{hi} a_{hi,z})^2} \qquad \text{Eq.(2)}$$

Where $a_{hi,x}$, $a_{hi,y}$, $a_{hi,z}$ are the RMS values of accelerations in m/s^2 measured along the x, y and < axes at the ith frequency; W_{hi} represent the weighting factors (see Fig. 4).

The table to be considered for the frequency weighting are those related to the ISO 5349 for vibration evaluation by HTV.

The aim of the weighting is to highlight certain particularly troublesome frequencies for the human body. In the present case, the weighting is carried out with the use of Table 1 extracted from the weighting curve reported in the ISO 5349. The application of that table consists into the filtering of the accelerations signal with appropriate set of filters centered in the next ith frequency defined in Table 1.

Table 1. Weighting factors for the HTV index

Frequencies [Hz]	Weighting factor W_{hi}
1	0.0235
2	0.1000
4	0.3981
5	0.5450
6.3	0.7270
8	0.8730
10	0.9510
12.5	0.9580
16	0.8760
20	0.7820
25	0.6470
31.5	0.5190
40	0.4110
50	0.324

The acceleration signal is filtered for each ith band and calculated the rms value $a_{hix,hiy,hiz}$. Finally, the RMS acceleration is multiplied for the ith frequency with the appropriate weighting value W_{hi} according to Table 1.

From this operation it is possible to calculate $a_{wx,wy,wz}$ that represents the frequency weighted acceleration along the three x,y,z axes.

The index, calculated for the three orthogonal directions x, y, z, is combined into a single index that defines the effective value of the frequency-weighted acceleration expressed as a combination of the accelerations measured on each individual direction using (1).

The HTV index presented previously has been calculated for each road profile in order to verify the feasibility of the aim

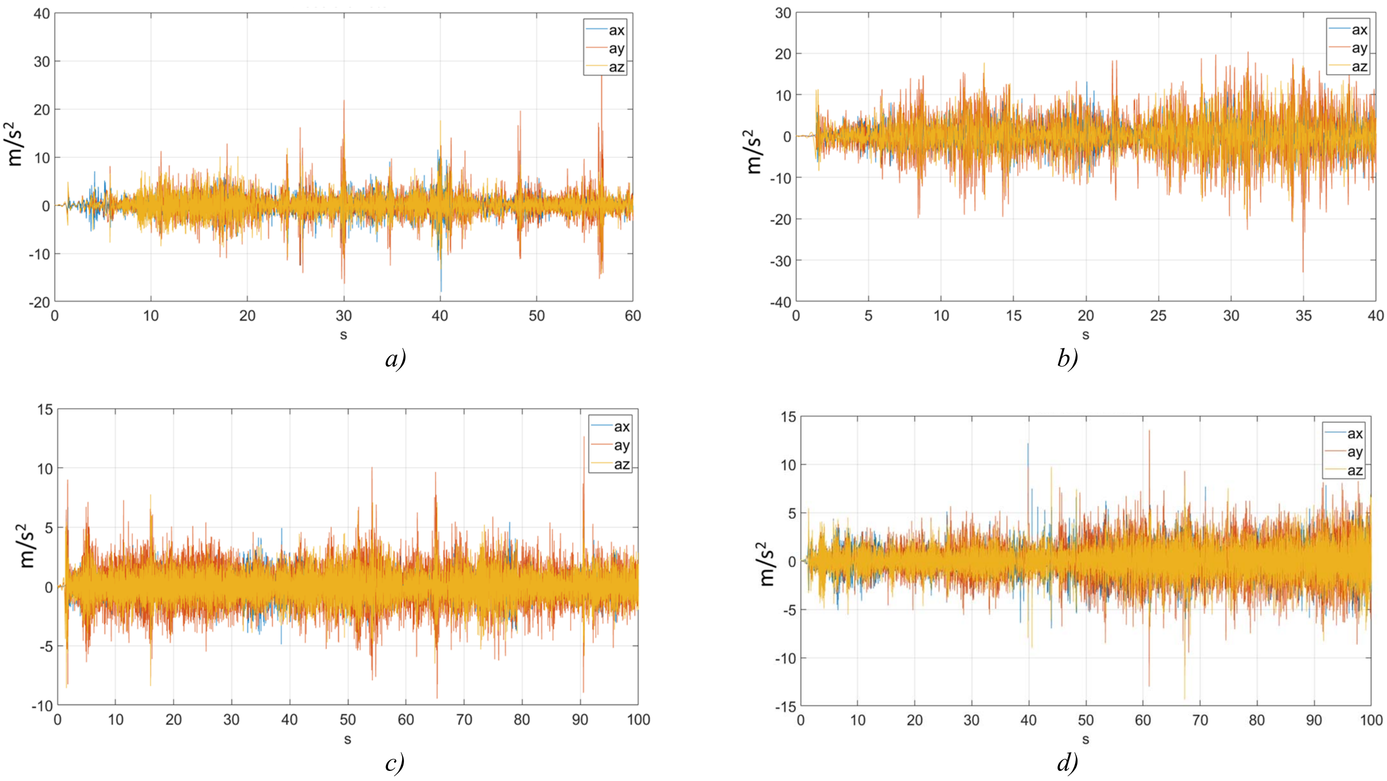

Figure 4. Acceleration signals: a) Urban road with irregular profile, b) Cobblestones, c) Extra urban road, d) Highway

proposed. Fig. 5 shown that the HTV indexed calculated for the cobblestone is the major among the HTV calculated for each road profile. This fact accomplishes with the physical behavior of the vertical dynamic of the motorcycle, where the maximum vibrations are generated when a strong vertical excitation is applied to the vehicle. The others HTV indexes are similar and lower than the one calculated for the cobblestone and in particular the sub-urban road has resulted to be the smallest. About the Highway, although is possible to figure a road profile very homogeneous than the other road profile considered, the HTV index has been result higher than sub-urban road mainly due to the influence of the aerodynamics in the vertical dynamics at high speed.

IV. Conclusions

The evaluation of the vibrations transfer to the human body during a motorcycles ride is a huge interest in order to give an important information to the rider about the stress accumulated during a ride. Considering the technological progress regarding the development of new tiny and wearable technologies, the paper has demonstrated the feasibility of the use of a normal wearable device (smart watch), for the calculation of the Hand Transmitted Vibration indexes for different road profiles. From the analysis of this indexes, it is clear that the highest value is relative to the cobblestone, then a long ride on a road surface of this type will bring a feeling of greater discomfort. On the contrary, the guide of the motor vehicle on a suburban road will involve less discomfort in driving.

Considering the results described, the method is useful also for the evaluation of the quality of the road surface that a driver is daily obliged to do for make usual path as the home-office way and give a feedback to choose the best road for reduce exposition to the vibrations (for example suburban road instead of highway). The measurement system described could be also used for the evaluation of the vertical vibration reduction introduced by a semi-active suspension system [17] instead of a classical suspension system in a motorcycle or detect fault conditions of suspension system **Error! Reference source not found.**-[20].

One of the main hypotheses of the proposal is the fixed position of the wearable devices on the left wrist, however, different

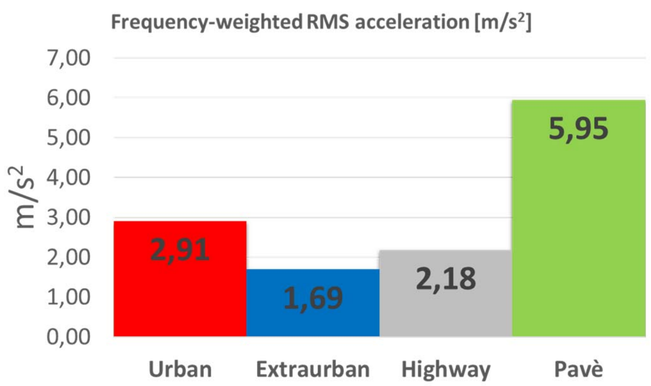

Figure 5. HTV indexes for the various road profiles considered

installation position will be investigated in order to give to the end user a multiplicative coefficient for the correction of the index.

Future research will concern the evaluation of the metrological performance of the proposed method with respect to a fixed reference system. Also, an analysis of the Whole Body Vibration (WBV) according to the ISO 2631-1 will be investigated introducing others wearable devices as *footpod*. Another possibility is to use also the frequency domain to evaluate the comfort of a vehicle.

The use of wearable devices able to calculate indexes according to the ISO normative without expensive fixed sensors on the motorcycle body, giving the possibility to calculate in real-time the HTV index also for different kind of vehicle, just wearing the smart watch.

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