Identification of Elders' Fall Using the Floor Vibration

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Abstract. This works investigates the possibility of identifying the elders' fall using accelerometers located on the ground. The work is divided in three parts: in the first we have designed a force platform to measure the forces generated during the fall and we have estimated the force generated by the impact of a subject with the floor using a crash test dummy. The effect of the dummy initial posture, of the presence of obstacles on the fall trajectory and of other parameters has been analysed as well. In the second part of the study we have analysed the vibration transmissibility in different dwellings. The final part of the research was focused on the estimation of the force starting from the vibration and from the impedance of the floor. Results have shown the possibility of identifying the elders' falls in the majority of dwellings.

Keywords: Fall detection · Vibration · Impedance

1 Introduction

The continuous improvement of living standard creates a new set of challenges for humanity. Lifespan incline of industrial nation's inhabitants becomes one of the major burdens of a today's society health care. Estimations show that by 2050 we could expect the number of elderly persons, living in their own home but requiring assistance, to triple [1]. The challenge of providing health care to elders even increases in such a case. Many examples demonstrated that in certain situations senior citizens are not capable of autonomously seeking a help.

One of the most hazardous scenarios is fall [1, 2]. Approximately 33% (range: 15 to 44.9%) of community-dwelling USA's elders older than 65 years and up to 60% of nursing home residents fall each year [3]. Falls are the leading cause of death injuries and are one of the major causes for injury-related hospitalization among senior citizens [4]. Different researches were performed all over the globe about elders' falls. For instance, in Swedish elderly people residential care facilities, most common fall locations were found to be bedrooms and bathrooms; the most frequently injured body parts were the head and the hips [5].

In order to help the older ones and at the same time to increase efficiency of health care service many devices and monitoring systems were designed. Most of methods were based on wearable sensors that would detect non-casualties among monitored

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person daily activities. Bourke and Lyons [6] worked on a threshold-based algorithm able to distinguish between activities of a daily living and actual falls using data measured by a mono-axial gyroscope.

Wu and Xue [7] analyzed the possibility of creating a portable pre-impact fall detector, a gadget that would be able to detect impending falls and then activate inflatable hip pad for preventing fall-related hip fracture. The instrumentation was based on commercially available sensors (triaxial accelerometers and triaxial angular rate sensors) attached to the subject.

Nevertheless, elders show a certain hostility to new technologies and there are cases when seniors refuse to wear instrumented clothes rather than the usual ones. In addition, the most common fall locations are bathroom and bedroom, where subjects are most of the time not wearing the detector. These considerations favor the development of falls detection systems relying on the monitoring signals coming from floor-mounted pickups rather than from wearable devices.

This work presents a feasibility study for the detection of elders' falls using the vibration measured by accelerometers fixed on the floor. The work is a part of the SMARTA project focused on the environmental monitoring for the active aging. There are different aspects that deserve investigation:

- the transmissibility of vibration in different kinds of residential floor have never been studied in the literature: given that the impact location will be in general at variable distances from the sensor positions, it is necessary to identify the vibration transmissibility in order to assess buildings dependent modifications of the signal;
- the force generated by people fall has been studied for frontal falls and rear falls of subjects [8–11]; however, results for elder people are expected to be very different, owing to their limited muscular force and to their reduced mental alertness; and
- In order to identify the fall without false alarms it is necessary to identify different classifiers capable of distinguishing between the falls of subjects, of objects and the common daily activities.

The paper is structured as follows: the proposed method is described in Sect. 2; Sect. 3 describes the preliminary tests. Experimental results are discussed in Sect. 4.

2 Materials and Method

The vibration generated by a fall is generally measured in a position different from that of the impact: consequently, different vibration pickups will measure different vibration time histories depending on their position. In addition, the force generated by the impact is unknown and there may be other events leading to vibration signals that might be similar to that deriving from people's fall. In this study, we have tried to address the first two issues, described in Sects. 2.1 and 2.2 respectively.

The proposed approach is summarized in Fig. 1: the vibration transmissibility through the different floors and the force generated from the different impacts are studied separately in order to be able to predict the vibration generated by different falls on the different floors. In other words, with the separate characterization of the force generated by an impact on an infinitely rigid floor and of the vibration transmissibility through the floor it will be possible to simulate a variety of combinations between impact locations, fall type and floor characteristics. These simulated signals will be used as training phase for the algorithms for the event detection, similarly to what was done in ref. [12].

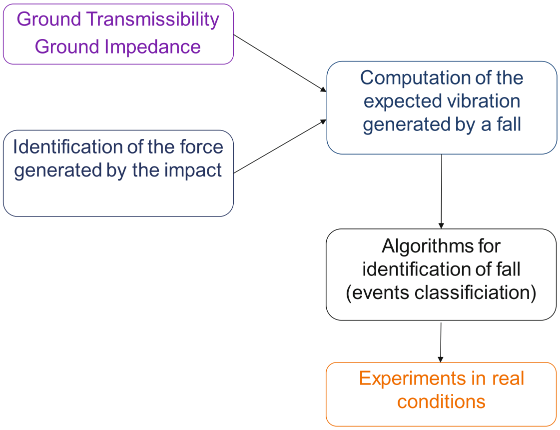


Fig. 1. Scheme of the proposed method.

2.1 Ground Transmissibility

The impact on the ground generates compressive and flexural waves that propagate through the floor from the impact position to the sensor(s) location. The subjects' fall can be identified by observing different features of the signal (in either time or frequency domain) and by using information about the impact location (to discard, for instance, shocks occurring in certain positions). The identification of signals' features requires the knowledge of the frequency response function (FRF) between the impact location and the measurement position while the different methods allowing the identification of the impact location on plates [12–14] require the knowledge of the wave speed in the plate.

The first step for the feasibility study is the identification of the floor vibration transmissibility in residential buildings. Since the vibration transmissibility depends on the mechanical and geometrical characteristics of the base and of the floor, experiments were performed to measure the vibration transmissibility in different conditions. For current purposes, four mono-axial accelerometers Bruel & Kjaer 4508 with nominal sensitivity of 10 mV/(m/s^2) measured the vibration at the positions indicated in Fig. 2; three accelerometers (indicated with the asterisk in the figure) were fixed, while one was moved close to the impact location. The vibration signals were sampled using a National Instruments NI 9234 data acquisition board. The sampling frequency was 2048 Hz in order to be able to evaluate the bandwidth of the stimuli, that were small jumps of a subject landing on the talons with straight knees. Preliminary tests showed that the stimulus' bandwidth was larger than the bandwidth of a subject falling forward on the hands or backwards on the buttocks. Under the hypothesis of linear behavior of the floor, any stimulus with a sufficient bandwidth can be successfully used to identify the vibration transmissibility, given that the transfer function of a linear system is independent from the stimulus.

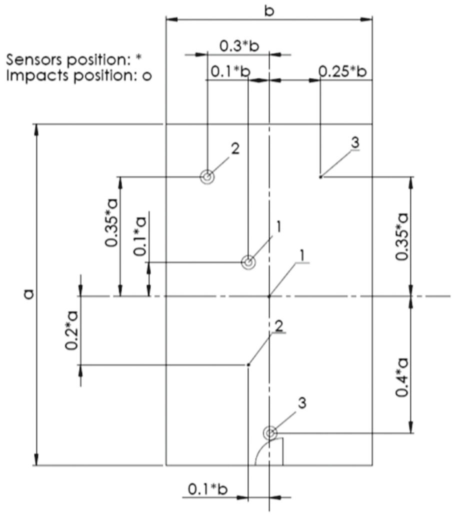


Fig. 2. Position of the accelerometers and of the impact in the transmissibility tests.

To date, the transmissibility has been measured in 30 different rooms, with surfaces between 2 and 50 m^2, with different pavement materials (wood, stones, tiles) and with different buildings (small residential buildings, condominiums). Tests are still ongoing, with the aim of having a comprehensive statistical description of the floor transmissibility. Experimental results have been summarized by averaging the vibration transmissibility of different buildings; the coherence function and the RMS of the vibration in "quiet" conditions have been evaluated as well.

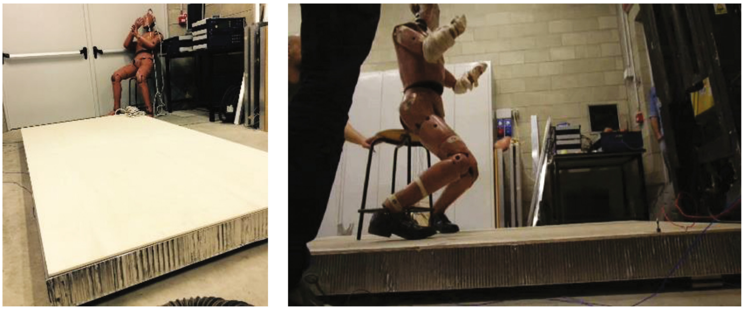
2.2 Force Generated by Different Falls

There are two separate problems in the identification of the force of elder subjects' falls: the first is the creation of a force platform with a surface of at least 2 m^2 with a sufficient bandwidth and the second is the creation of a test protocol allowing the simulation of different kinds of falls.

The force platform has been realized using a sandwich honeycomb panel (2.5 × 1.25 m) supported by four piezoelectric load cells PCB 211B. The overall sandwich thickness is 100 mm, with sheets thickness of 1 mm and honeycomb thickness of 50 μm. The theoretical computations pointed out a first resonance frequency of approximately 85 Hz. The dynamic behavior of the force platform has been experimentally verified with an impact hammer and outlined that the frequency pass-band (±3 dB) is 40 Hz. The test protocol includes two groups of tests:

- fall simulations performed by 21 healthy subjects (18 males, 3 females, ages 23–32) falling forward with different arrest strategies: tests are performed on the force platform by healthy subjects starting from standing and sitting posture; the subjects' average weight was 73 kg (standard deviation 12 kg) and the average height was 182 cm (standard deviation of the sample 9 cm);
- fall simulation performed by a dummy: a Humanetics pedestrian dummy (Hybrid III 50th Percentile) is used to identify the force of forward, backwards and lateral falls, upon varying the upper limbs posture.

After the plate metrological calibration, preliminary tests were performed to verify the time histories and the spectral features of the vibration and force signals generated during the impact. A picture of the experimental setup is shown in the figure below.



(a) (b)

Fig. 3. Pictures of the force plate and of the Humanietics dummy.

3 Results

3.1 Ground Transmissibility

The average transmissibility measured in the first 30 tests is shown in Fig. 3a and the average coherence between the input and output positons (asterisks and circles in Fig. 2) is shown in Fig. 3b. Plots include the effect of the different rooms' sizes, of the floor mechanical characteristics and of the different positions of the impact/sensor.

Results show that FRF modulus is averagely lower than 1 in the band between 0 and 150 Hz. The average transmissibility is low below 15 Hz, but the minimum value (0.3) is not critical [15] and does not prevent the measurements in that region. The coherence is larger than 0.8 between 20 and 80 Hz.

The vibration transmissibility and the coherence function depend on the floor type and on the room size: the transmissibility measured on the wooden floors are averagely lower than that on the tiles and stones, especially at high frequencies. As expected, the first resonance frequency depends on the room size, while the effect of the furniture is small in comparison with the effects of floor type and room size (Fig. 4).

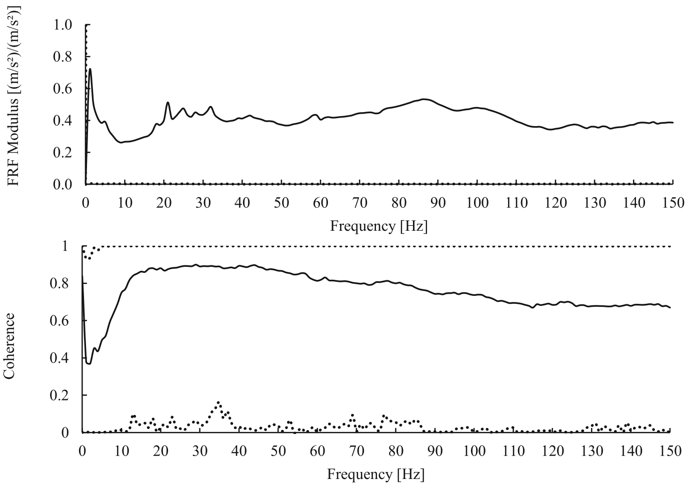


Fig. 4. Averaged transmissibility of the room that underwent to our tests (upper plot) and average coherence of the transmissibility tests (lower plot). Solid lines show the test average, dotted line indicate the maxima and minima measured during the tests.

3.2 Impact Force

Preliminary tests were performed by simulating the forward fall of healthy trained subjects; the impact occurred with the hands on the force platform. Both force and vibration signals were measured. The total dynamic force measured by the four load cells of the force platform (in the range between 1 and 40 Hz) is shown in Fig. 5. The plots show the dynamic forces due to the impact of a subject falling forward from standing position in two tests; although many other tests were performed, results cannot be reported here for sake of brevity.

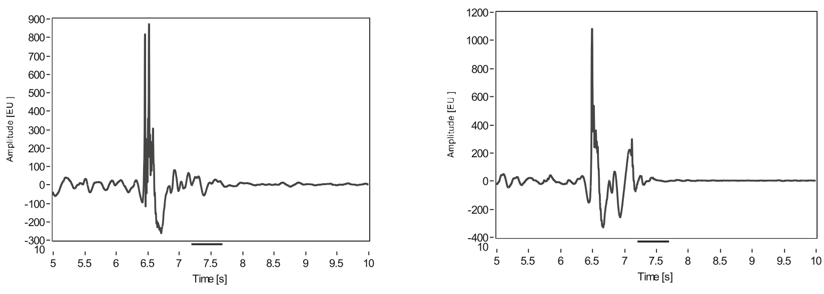


Fig. 5. Time histories of two front falls (Force [N] versus time, frequency range between 2 and 40 Hz)

The frequency content of the signals was at first analyzed using the short-time Fourier transform, but the technique did not allow separating the closely spaced impulses with a sufficient frequency resolution. The problem was overcome by using

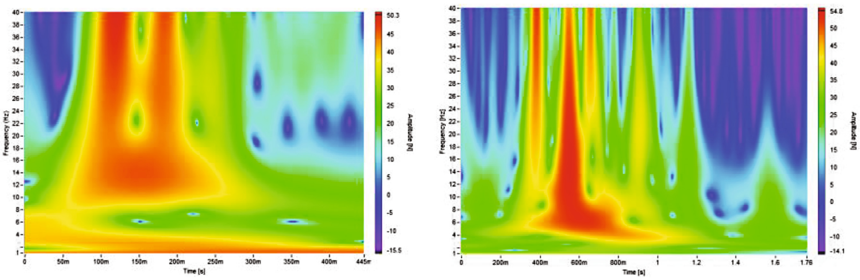


Fig. 6. Wavelet transform of the front fall (left) and back falls (right). Logarithmic scale.

the wavelet transform (4096 scales, time increment of 1 ms); results (Time histories of the left plots in Fig. 5.) are shown in Fig. 6.

In the forward fall, the two impulsive events deriving from the contact of the two hands have a similar frequency content, mostly concentrated at frequencies larger than 8 Hz. In the rear fall, the impulsive events deriving from the impact of the hands have noticeable energetic content above 20 Hz, while the buttocks absorb energy also at lower frequencies. In both front and rear falls, the force spectra include frequency components up to 40 Hz, thus allowing the choice of wide frequency ranges for the identification of falls starting from the floor vibration signals.

The forces generated by the fall of objects were different from those measured during the fall of subjects in terms of both force peak amplitude and event duration, as shown in Fig. 7, evidencing the possibility of discriminating the different events on the basis of the event magnitude and spectral characteristics [16].

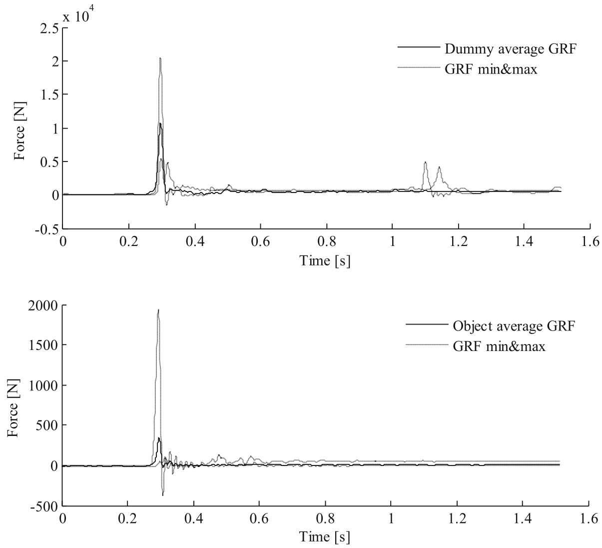


Fig. 7. Wavelet transform of the front fall (left) and back falls (right). Logarithmic scale.

4 Discussion and Conclusions

The results of the feasibility study presented in this paper are encouraging, since the frequency of the fall-generated excitation and the region in which the vibration transmissibility is high are overlapped. The vibration transmissibility is suggesting that in rectangular rooms it is possible to measure the vibration at any position of the room, independently on the impact location, so theoretically one accelerometer will be enough for measuring flexural vibrations. The optimal transducer location will be studied in forthcoming studies, but thanks to the low cost of the MEMS transducers it seems reasonable to put more than one sensor in different room locations. Preliminary analyses showed that the simultaneous use of more transducers allows identifying the impact location, thus allowing a more robust event identification.

The results of the fall-generated excitations presented in this paper were based on falls simulated by young and healthy people; the next steps of the research will be the characterization of the forces generated by falls performed with the instrumented pedestrian dummy and the comparison of different signal processing techniques for the identification and possibly classification of the different types of fall. The research will focus on the identification of the possible features for the signals' classification and on the numerical simulations meant to identify how the ground impedance modifies the force signal at different locations.

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