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Material characterization by surface wave parameters extraction using 3D vibrometer and ellipsometry

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Abstract. This work focuses on the monitoring of the 3D propagation of ultrasonic surface waves used in non-destructive testing and evaluation. The ellipticity of the movement related to the Rayleigh wave, specifically the H/V parameter, is studied analytically, numerically, and experimentally on an aluminum block. The study involves generating signals from the theoretical harmonic expression of particle displacement issued from Rayleigh wave, carrying out numerical simulations using a finite element method, and generating the Rayleigh wave using a shear contact transducer with a 1 MHz central frequency in the experimental study. The work also involves appropriate filtering of signals to extract components with specific polarization and suppress other modes with low polarization energy. The obtained results for aluminum show a good agreement between the analytical, numerical, and experimental studies of Rayleigh wave ellipticity. Moreover, these H/V ratios are consistent with the theoretical values described in the literature. As a proof of concept, this method is also applied to simulation data to study orthotropic materials (wood/bone), obtaining promising results.

1. Introduction

Surface acoustic waves (SAW) such as Rayleigh waves [1] can be used as a material investigation tool in cases where direct contact with the object is difficult or not possible. This condition is necessary in the case of application in the non-destructive testing and evaluation of cultural heritage objects, where direct contact is often prohibited due to the fragile and delicate nature of the objects and materials. As their name suggests, SAW propagates on the surface of the material, giving them the advantage of being accessible, and directly measurable, contrary to bulk waves. Rayleigh waves have a low attenuation while propagating on the surface of objects, as their energy stays confined at the surface, meaning that they can cover a relatively large distance. These properties make them appropriate for the development of an acoustic contactless non-destructive method. The contactless aspect is assured by using a 3D laser vibrometer to extract the three components of particle displacement generated by the SAW [2]. The extraction of the 3D surface displacement from Rayleigh wave propagation highlights its elliptic nature [3]. The elliptic motion can be characterized by two parameters, the ellipticity ($\chi = H/V$) calculated from the ratio between the in-plane (H) and the out-of-plane (V) motion of the Rayleigh wave, and the orientation of the ellipse (θ) which is the angle between the major axis of the ellipse and the horizontal axis. These two geometric parameters are related and evolve as functions of the mechanical properties of the material.



Before the technological advancement in laser vibrometry, the three components of the vibration of surface waves were first measured by geophysicists using directional geophones. The access to these measurements allowed them also to be the first to use the ellipticity of Rayleigh waves to characterize the soil. The H/V spectral ratio, *i.e.* the ratio between the Fourier amplitude spectra of the horizontal and the vertical components of Rayleigh waves generated by microtremors, was introduced in 1971 by Nogoshi and Igarashi [4], but it was made popular by Nakamura [5,6]. A correlation between the H/V spectral ratio and the fundamental resonance frequency of the observed geological site is highlighted by these authors. The simplicity and efficiency of this method made it very popular in geophysical studies and applications. Molnar et al. did a literature review on the historical development of the microtremor H/V spectral ratio method, proposed recommendations regarding the acquisition, the analysis of signals and the interpretation of the results [7].

Regarding the theoretical modeling of the variation of H/V as a function of the mechanical properties of the material, Malischewsky developed a model relating the H/V ratio to the values of longitudinal, shear, and Rayleigh waves velocities for an isotropic half-space and multi-layered medium [8], and Vinh et al. have developed a model for an orthotropic elastic half-space [9]. In parallel to the advancement in theoretical modeling, laser vibrometry and material characterization using this kind of instrumental system were in full development, starting with Aussel and Monchalain proposing an elastic constants determination technique using precise laser-ultrasonic velocity measurement [10]. Orta et al. developed a semi-analytical finite element method to identify orthotropic elastic stiffness using 3D vibrometry measurement of guided waves [11]. Staszewski et al. did an overview on the use of Laser Doppler vibrometry for structural health monitoring [2].

In 2006, Bayon proposed a contactless method for the estimation of the dynamic elastic constant of an isotropic material, by merging the theoretical model of H/V in the isotropic case with the 2D laser vibrometer to extract the amplitude of the two components in the sagittal plane of a propagating Rayleigh wave. The theoretical model suggested by Malischewsky is inverted in order to estimate Young Modulus (E) and Poisson ratio (ν) from the H/V ratio and the value of Rayleigh wave velocity, with good accuracy 0.82% for E and 4.4% for ν [3]. This accuracy is guaranteed under the hypothesis of extracting a pure Rayleigh wave from the surface displacement of the material, as the estimation of the H/V value is done on the spectral domain of the presence of another type of waves which overlaps with the spectrum of desired Rayleigh wave, and thus this will introduce errors in the estimation of the mechanical properties.

However, laboratory conditions regarding the extraction of the two components of Rayleigh wave are not always guaranteed. In practice and on the field, the extracted signals contain different types of waves and noise generated by uncontrolled sources. All these additional waves interfere with the Rayleigh wave, introducing errors in the estimation of H/V.

In the H/V spectral ratio method, the two components H and V are processed separately. The spectrum of each of the components is calculated independently and then the ratio is estimated using a simple division. This last approach is very sensitive to noise and to other undesired waves in the signal. To overcome this, the bivariate signal processing frame provides tools, such as the Hermitian linear time-invariant filters, to estimate the eigenpolarization of a bivariate signal, considering both components of the signal at the same time [12]. The eigenpolarization is the dominant polarization (a set of values for the ellipticity χ and orientation θ) in a bicomponent signal. In our case despite the presence of other waves and noises on the extracted signal the energy carried out by the Rayleigh is significantly higher, this ensures that the dominant polarization is also that of the Rayleigh wave, which is the targeted value to be estimated using Hermitian filters.

In this paper, the theoretical background regarding the H/V value in the case of an isotropic half-space, and its sensitivity to the measurement errors, will be presented first, then the Hermitian filters method for the estimation of the eigenpolarization of the bivariate signal, the validation on a theoretical signal, finite elements simulation signal. After the validation, the experimental setup used to extract the signals and the results obtained using the Hermitian filters will be presented and discussed.

2. Theoretical background

In this first part, the theory behind the proposed contactless non-destructive evaluation method is presented, starting with the inverse model allowing us to estimate the Young modulus and the Poisson's ratio from the value of H/V and the velocity of Rayleigh wave, followed by a study of the sensitivities of this expression to the measurement errors, and finally the Hermitian filters and the approach used to estimate the polarization of a bivariate signal.

2.1. The expression of H/V ratio

In a homogenous isotropic half-space, Rayleigh waves propagate on the surface, with the energy confined within a depth in the order of the wavelength of the wave. For a harmonic monochromatic excitation, the relation between the phase velocities of longitudinal V_L , Transversal V_T and Rayleigh V_R waves is given by the following equation [3,13]:

$$R^3 - 8(R - 1)(R - 2 + 2\kappa^2) = 0 \quad (1)$$

where $R = V_R^2/V_T^2$ and $\kappa = V_T/V_L$

In the sagittal plane, defined by the plane normal to the surface and to the propagation direction, a particle undergoing the deformation of Rayleigh wave has an elliptical retrograde motion. The two components defining the elliptical motion are $\pi/2$ out of phase, generating an orientation $\theta_R = \pi/2$, meaning a vertically oriented ellipse. The H/V value is defined as a function of V_L and V_R by the following [8]:

$$\chi_R = \frac{H}{V} = 2 \frac{\sqrt{1 - \frac{V_R^2}{V_T^2}}}{2 - \frac{V_R^2}{V_T^2}} = 2 \frac{\sqrt{1 - R}}{2 - R} \quad (2)$$

For an isotropic half-space V_R and V_T are independent of the frequency of the excitation, this makes the H/V ratio non-dispersive. The values of V_R and V_L depend on the mechanical properties of the material, Young modulus (E), Poisson ratio (ν) and the density (ρ) [13]. An inverse problem is developed relating the mentioned mechanical properties to H/V value and V_R [3]. This direct relation means that the errors on the measurement of H/V and V_R will induce errors in the estimation of E and ν . To quantify this error, the relative error of χ_R regarding a relative error of $r = V_R/V_T$, is calculated from equation (2):

$$\frac{d\chi_R}{\chi_R} = \frac{-r^4}{r^4 - 3r^2 + 2} \cdot \frac{dr}{r} \quad (3)$$

r can take a value in the interval $[r_{min} = 0.874, r_{max} = 0.955]$ [13], the relative error on the estimation of H/V ($d\chi_R/\chi_R$) for a 10% relative error on the estimation of r ($dr/r = 10\%$) can change as a function of r itself, but it is confined between the following two values :

$$\left. \frac{d\chi_R}{\chi_R} \right|_{r=r_{min}} = -19.99\% \quad (4)$$

$$\left. \frac{d\chi_R}{\chi_R} \right|_{r=r_{max}} = -86.90\%$$

These findings demonstrate how the equations that determine the H/V variation are affected by small changes in the estimation of χ_R . If V_T/V_R is estimated with an error margin of 10%, then the minimum error in estimating χ_R is around 20%. However, the extent of this error can be as high as 87%, this depends on the material being studied. These results highlight the importance of having a good measurement of the H/V ratio.

2.2. Hermitian filtering and estimation of χ and θ

In the sagittal plane of a propagating Rayleigh wave, only the components normal and tangent to the direction of propagation of the wave change as the wave propagates. This aspect makes the extracted signals in the sagittal plane a bivariant signal. The bivariant signals framework provides tools for processing signals with two components. The advantage of this framework is that the two components are treated at the same time, not in a separate process, as is the case for the H/V spectral ratio method.

Hermitian filter is a type of linear time-invariant filter. This type of filter works on the frequency domain and performs a Hermitian transform at each frequency contained in the input bivariant signal, modifying both the power and the polarization (χ, θ) properties of the input signal [12]. The diattenuation axis of the filter represents the set of values of χ and θ , or the polarization, at which the gain of the filter is maximum, this polarization represents the eigenpolarization of the filter. The value of this polarization is one of the parameters of the filter, meaning that it can be changed to a desired value, allowing us to detect if the input signal has the same polarization as the one of the Hermitian filter by verifying if the gain is at maximum. One Hermitian filter can detect one value of polarization. For that, we will need a bank of these filters, allowing us to detect the value of the polarization of the input signal over the range of the possibilities.

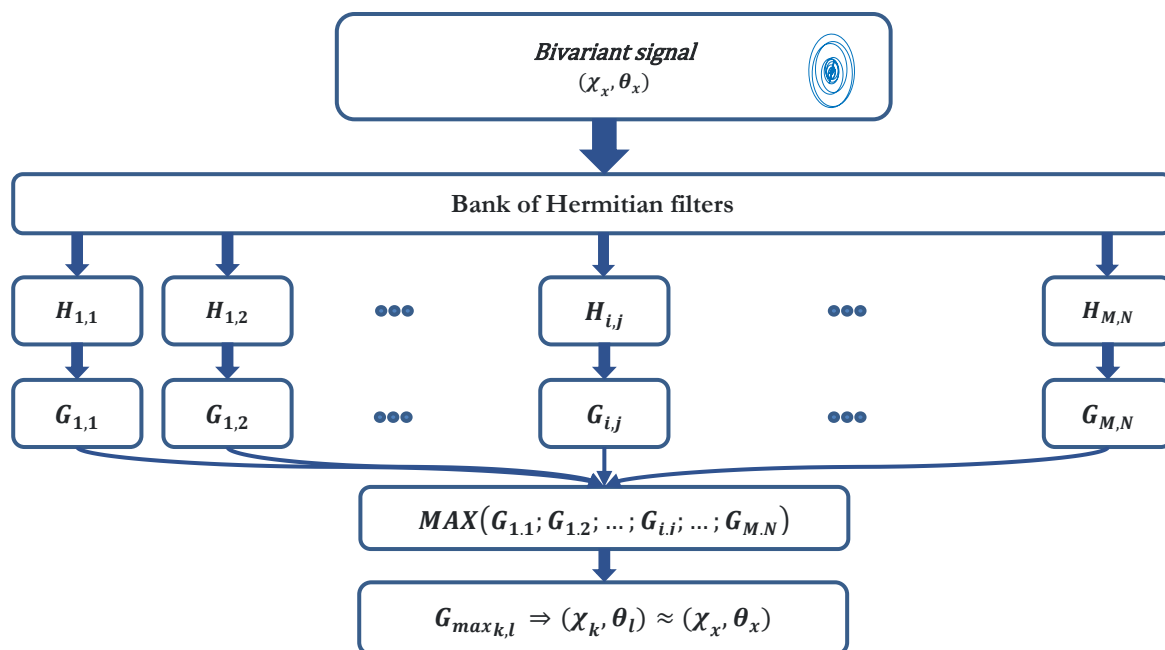


Figure 1: The information flow used to estimate the ellipticity parameters.

Figure (1) illustrates the process followed to estimate the value of the polarization, at first the bivariant signal is passed through the filters with different eigenpolarization, and then the gain at the output of each filter is calculated. The polarization parameters of the filter with the maximum gain are recovered. The recovered parameters correspond to the dominant polarization of the input signal.

The values of the ellipticity vary in the range $\chi \in [-1 ; 1]$ and the orientation varies in the range $\theta \in [-\pi/2 ; \pi/2]$, to establish the filters for the benchmark, the range of values of these two intervals are discretized with a fixed step, where small steps give a precise estimation of the polarization at the cost of longer calculation time. In Figure (1) the subscripts i, j correspond to the indexes of the value taken from the discretized intervals of variation of χ and θ respectively, M and N are the total numbers of values for χ and θ respectively. The gain value for each filter can be plotted as a function of χ and θ , this allows us to better visualize the variation of gain and the position of the maximum.

This approach allows us to better estimate the polarization parameters of a Rayleigh wave from a time signal extracted in a situation where not only a Rayleigh wave is propagating, but different types of noise are present. In the next part, this method will be tested at first on a theoretical signal, then on a signal extracted from a finite element simulation, and finally on an experimental signal.

3. Validation

Different kinds of signals are used in this study to evaluate the ability of the bank of Hermitian filters to accurately estimate the polarization parameters of a bivariant signal obtained from the sagittal plane of a propagating Rayleigh wave. The first signal is a synthetic monochromatic signal with fixed polarization parameters. The second signal is obtained from a finite element simulation of a Rayleigh wave propagating on the surface of an aluminum block. Lastly, the third signal is obtained using a 3D vibrometer to measure a Rayleigh wave propagation on the surface of an aluminum block.

3.1. Synthetic theoretical signal

For a material such as aluminum with a longitudinal sound wave velocity of $V_L = 6374 \text{ m/s}$ and shear wave velocity of $V_T = 3111 \text{ m/s}$. The equation (2) governing the propagation of a monochromatic Rayleigh wave on an isotropic half-space, predicts that $\chi = 0.626$ and $\theta = \pi/2$ rad. Based on these values a bivariant signal can be synthesized (Figure (2)) and passed through the bank of Hermitian filters.

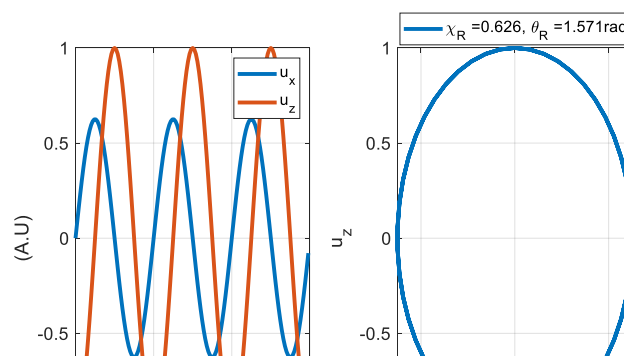


Figure 2: Synthetic bivariant signal for Rayleigh wave.

In Figure (2) the two components of a Rayleigh wave in the sagittal plan (u_x, u_z) are plotted on the left axis, on the right axis the variation of u_z as a function of u_x is plotted, this highlights the elliptic shape.

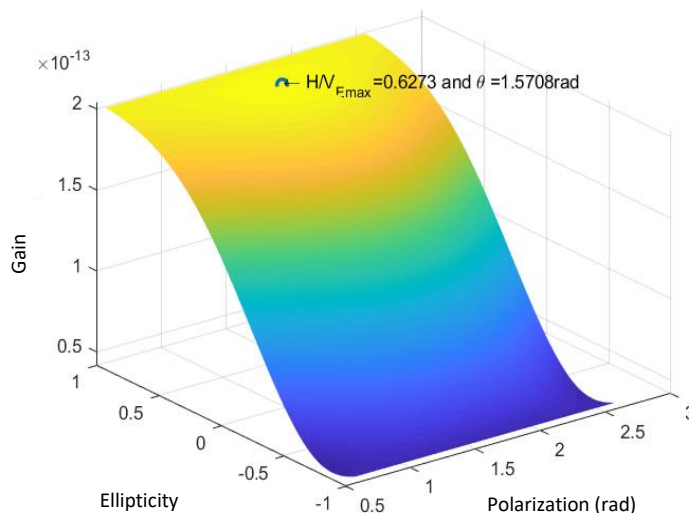


Figure 3: The gain as a function of χ and θ for the synthetic signal.

Figure (3) shows the variation of the gain of different Hermitian filters as function of $\chi = H/V$ and θ . It is clear that for the synthetic signal, the gain changes as a function of χ and θ . The polarization corresponding to the maximum value of the gain is $\chi=0.627$ and $\theta=1.571$ rad. The relative error on the estimation of the parameters are $Err_{\chi} = 2.1 \cdot 10^{-1}\%$ and $Err_{\theta} = 2.3 \cdot 10^{-3}\%$. In the case of a synthetic perfect signal, these results validate the capacity of the bank of Hermitian filters to estimate the parameters of the polarization of a bivariate signal.

3.2. Simulation signal

The following numerical simulation allows us to generate more realistic signals, signals that contain not only the propagating Rayleigh wave but also other types of waves. Also, different types of materials and geometric shapes of the objects can be easily simulated and studied. As this work is only interested in the particle displacement generated on the sagittal plane of the wave, a 2D simulation will be enough to extract a bivariate time signal. A finite element method simulation is performed, allowing a time and space discretization of the propagation of a Rayleigh wave on the surface of an isotropic aluminum block, with the following properties: Young Modulus $E = 69 \text{ GPa}$, Poisson ratio $\nu = 0,33$, density $\rho = 2730 \text{ kg/m}^3$. The excitation is a 6 cycles tone burst with a central frequency of $f_0 = 1 \text{ MHz}$. At this frequency the wavelength of Rayleigh waves is around $\lambda = 3 \text{ mm}$, the depth of the simulated 2D block is $l = 10 \text{ cm}$, this value relative to the wavelength allows us to assume that the wave is propagating on an infinite half-space. Each cycle of excitation corresponds to one extracted ellipse. Having multiple cycles (ellipses) provides a more accurate polarization estimation. The studied propagation problem is solved using a time dependent solver, the time step between two iterations is fixed to $dt = 1/(10 \cdot f_0)$. The simulated geometry is discretized with a triangular mesh, the maximum element size is fixed to one-tenth of the wavelength of shear waves, because they have the shortest wavelength, $L_{Max} = V_T/(10 \cdot f_0)$.

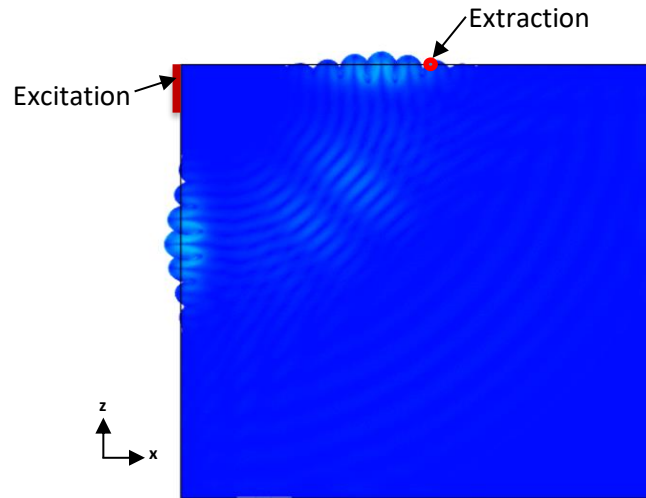


Figure 4: Wave propagation at time $t_i = 15\mu\text{s}$.

Figure (4) illustrates the deformation of the propagating Rayleigh wave at the time $t_i=15\mu\text{s}$, the position at which the signal is extracted and the position of the excitation force applied on the $-z$ direction.

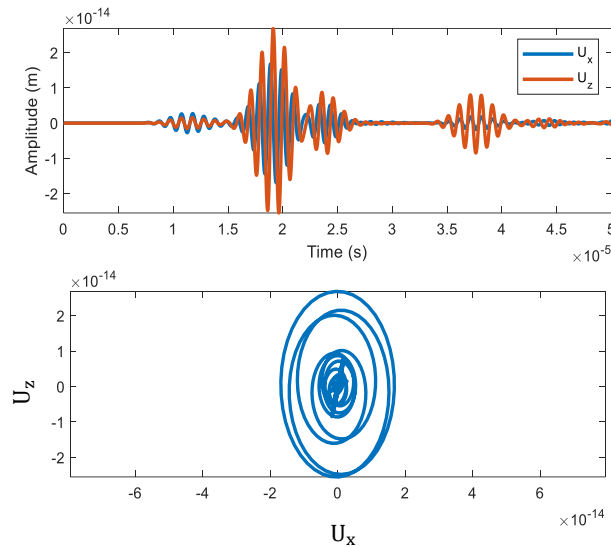


Figure 5: Bivariant signal extracted from the simulation.

The extracted temporal signal is shown in the top of Figure (5), and the other part of the figure presents of u_z as a function of u_x . Contrary to the synthetic case, the signal is not monochromatic and contain different types of waves, as we can see in the different phase delays between the two components of different wave packets. In the extracted signal, the dominant polarization or eigenpolarization is that of the Rayleigh wave, despite the presence of other types of waves. The amplitudes of the other waves are lower than that of the Rayleigh wave. By using the material properties implemented in the simulation, the theoretical $\chi = H/V$ value can be calculated, as V_L and V_T can be directly derived from E and ν [13], and V_R can be estimated by equation (1). The theoretical values of $\chi_{theo} = H/V_{theo}=0.640$ and $\theta = \pi/2$ rad, these values are used to validate the results estimated by the bank of Hermitian filters.

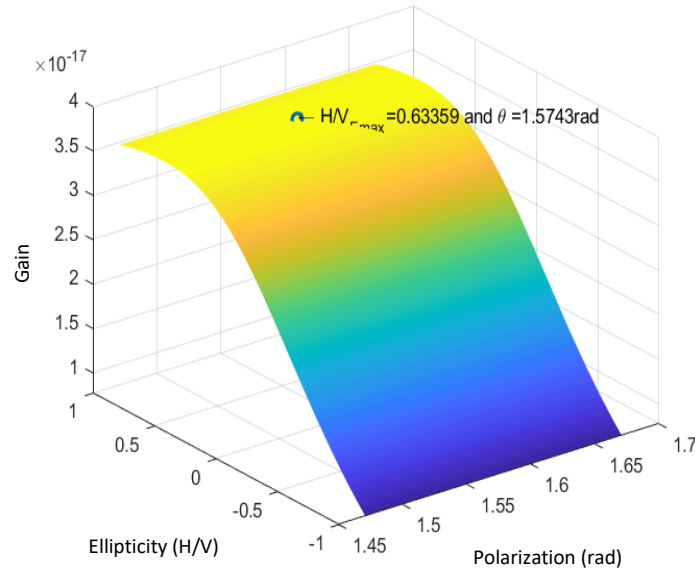


Figure 6: The gain as a function of χ and θ for the simulation signal.

Figure (6) illustrates the results obtained by the bank of filters, the gain as a function of χ and θ , for the case of a simulated signal. For this signal, the maximum gain is at the output of the Hermitian filter with the parameters: $\chi = 0.633$ and $\theta = 1.574$ rad, the relative error between these values and the theoretical ones is as follows: $Err_{\chi}=1.1\%$ and $Err_{\theta}=0.2\%$. Despite the presence of other types of waves interfering with the Rayleigh wave, the presented method can estimate with good accuracy ($< 2\%$) the polarization properties of the Rayleigh waves and therefore allow a better estimation of mechanical properties of the medium.

3.3. Experimental signal

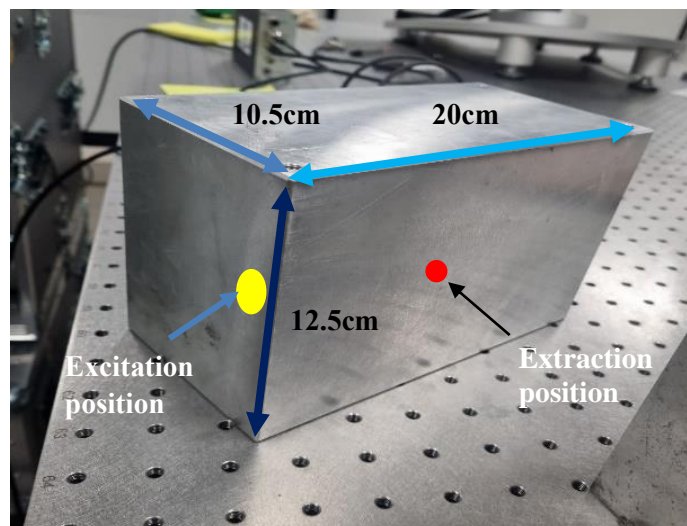


Figure 7: Aluminum block used in the experiment.

The final step in the validation process is to apply the proposed method on a real experimental signal extracted from a propagating Rayleigh wave. A block of aluminum (Figure (7)), with the dimensions $20 \times 12.5 \times 10 \text{ cm}^3$, is used as a support for the propagation of the waves, $V_R = 2888 \text{ m/s}$ and $V_T = 3092 \text{ m/s}$ are respectively the values of the velocity of Rayleigh and shear waves on the

block. The surface wave is generated using a shear wave transducer mounted on the side of the block, with a central frequency of $f_c = 1\text{MHz}$. The transducer applies a force tangent to the surface, this will generate a Rayleigh wave in the adjacent face [14], the signal is extracted in the sagittal plane of the wave, as shown in Figure (7).

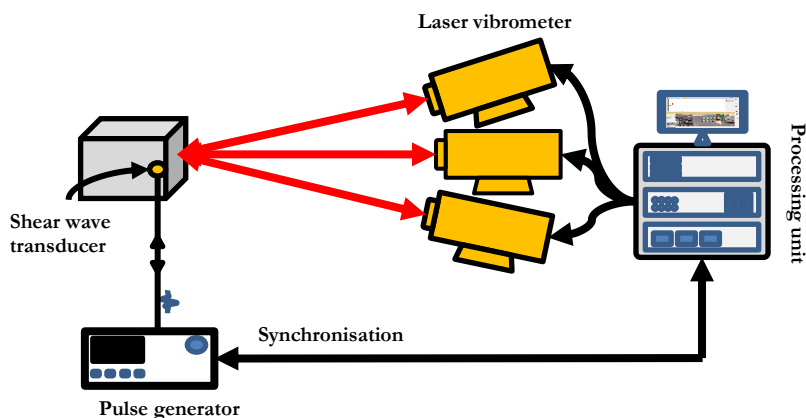


Figure 8: Experimental setup.

The block and the transducer are mounted in the experimental setup shown in Figure (8). The side, on which the wave is propagating, is facing the vibrometer. The excitation and the synchronization signals are generated by the pulse generator. The time signals of the three components of the displacement (u_x, u_y, u_z) are extracted using the Polytec Laser Vibrometer ® *PSV 500-3D-M*, this vibrometer can measure signal with frequencies up to 25MHz . The extraction can be done on a single point or over a grid of predefined points.

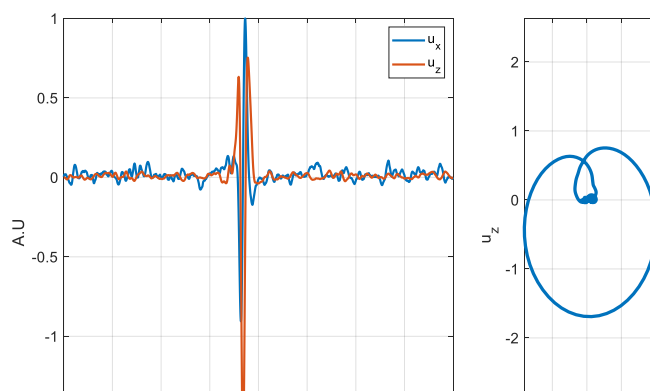


Figure 9: Bivariant signal extracted from the experimental setup.

The bivariant signal extracted from the indicated point in Figure (7) is shown in Figure (9). In this figure, one can see that for the experimental case the signal contains noise, which was not present in the previous cases. This signal is analyzed by the bank of Hermitian filters, and the results regarding the variation of the gain as function of χ and θ are recovered as illustrated in Figure (10).

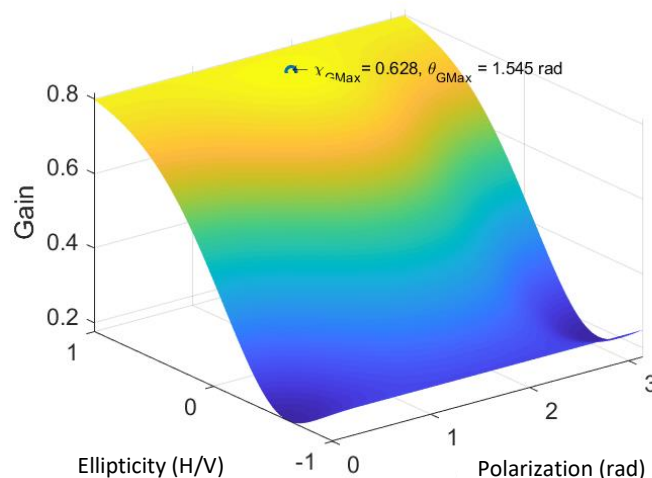


Figure 10: The gain as a function of χ and θ for the experimental signal.

From the values of V_T and V_R for the aluminum block, and by using equation (2), we can estimate the theoretical value of $\chi_{theo} = H/V = 0.634$ and $\theta_{theo} = \pi/2$ rad. The presented method estimates these two parameters for the experimental case to be: $\chi_{exp}=0.628$ and $\theta_{exp}=1.545$ rad. The relative error between the theoretical values and the estimated experimental values are as follows: $Err_{\chi}=0.9\%$ and $Err_{\theta}=1.6\%$. The calculated relative error is very small, meaning that despite the noise present in the signal extracted from the experimental setup, the bank of filters can correctly estimate the polarization parameters of the propagating Rayleigh wave.

For the three types of signals, synthetic, numerical and experimental, the bank of filters showed good results (Table 1) regarding the estimation of the values of the ellipticity and the orientation of the polarization of Rayleigh wave propagating on the surface of a material, as discussed in the theoretical background having a good estimation of the $\chi = H/V$ is the key to properly estimate the mechanical properties (E, ν) of the material.

Table 1 : Summary of the obtained results.

Type of signal	χ_{theo}	θ_{theo}	χ_{estim}	θ_{estim}	Err_{χ}	Err_{θ}
Synthetic	0.626	$\pi/2$	0.627	1.571 rad	$2.1 \cdot 10^{-1}\%$	$2.3 \cdot 10^{-3}\%$
Simulation	0.640	$\pi/2$	0.633	1.574 rad	1.1%	0.2%
Experimental	0.634	$\pi/2$	0.628	1.545 rad	0.9%	1.6%

4. Application on different materials

In this section, the bank of filters is used to estimate the polarization of simulated Rayleigh waves propagating of different types of materials (wood, bones), to see the variation of the ellipticity of the wave as a function of different parameters such as the wood species or the post-mortem interval of the bone.

4.1. Wood: two different species

Wood is widely used in cultural heritage objects, such as in musical instruments, canvases of paintings, ancient furniture, buildings and much more. It is of great importance to distinguish which species of wood is used in old objects to carry out restoration in case of damage. In this part, the aim is to check if the $\chi = H/V$ parameter varies for different species of wood. To verify that, simulations of Rayleigh waves propagating on two different species of wood were carried out. The first species is a

softwood known as DOUGLAS FIR, and the second species is a hardwood known as SWEETGUM. As their classes indicate, these two kinds of woods have very different rigidities and represent the two upper and lower bounds regarding the rigidity of wood, these will give us an idea on the interval of variation of χ as function of the rigidity of the wood, which material properties of the two species of wood used in the simulation, the stiffness tensor, and the density of orthotropic wood with 12% humidity (dry state), are extracted from the Wood handbook [15]. Only the simulation of propagation on the RL plane, i.e. the plane containing the fibers axis of the wood, is done to save calculation time. The following figures illustrate the bivariate signal extracted from the simulation and the results of the estimation of the polarization parameters using the bank of Hermitian filters (Figure (11) for the softwood DOUGLAS FIR and Figure (12) for the hardwood SWEETGUM).

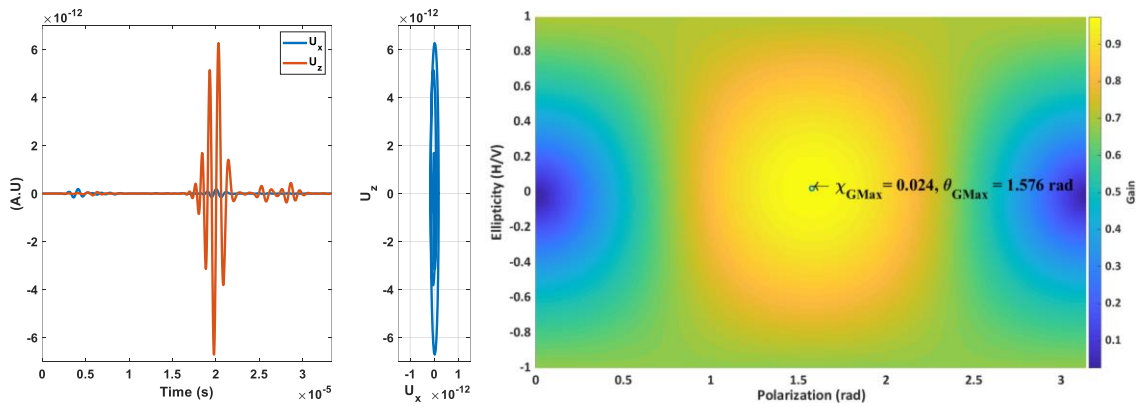


Figure 11: The extracted signal and the gain as a function of χ and θ for the DOUGLAS FIR wood.

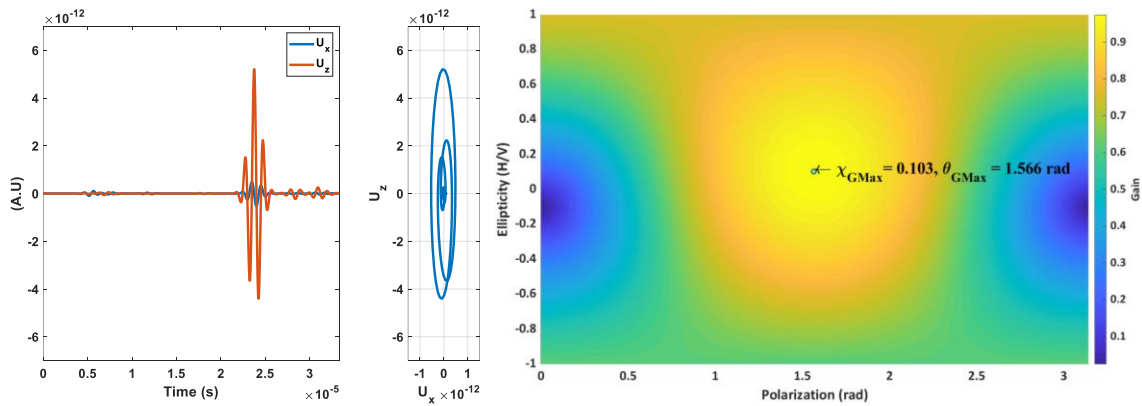


Figure 12: The extracted signal and the gain as a function of χ and θ for the SWEETGUM wood.

The obtained results are: $\chi_{DOUGLAS\ FIR}=0.024$ and $\chi_{SWEETGUM}=0.103$. Compared to the value of aluminum ($\chi_{Al}=0.625$) one can note that the wood has lower values of ellipticity. This last can be explained by the orthotropic nature of wood, meaning that the deformation of the material is more difficult in some directions than others. In the case of the simulated woods, the deformation in the normal direction is easier than the one in the tangent direction [16], as one can see in the relatively big difference in amplitude between the components u_z and u_x of particle motion. The two different species of wood have different values of χ , with the hardwood having the highest value with a factor of 5. A distinction between these two classes of wood could be made based on χ . The two chosen species of wood represent the two extreme limits of the rigidity of woods, and one can say that the ellipticity of Rayleigh waves propagating on the RL plane of a wood with a rigidity laying between DOUGLAS FIR and SWEETGUM would be $\chi_{DOUGLAS\ FIR}=0.024 \leq \chi_{Wood} \leq \chi_{SWEETGUM}=0.103$.

4.2. Bones: different post-mortem intervals (PMI)

The estimation of the post-mortem interval of bones is of great importance in archaeology and criminology. In this part, the propagation of Rayleigh waves on bones with different PMI are simulated, and their polarization properties are extracted using the bank of Hermitian filters. The simulations are carried out using the rigidity tensor of bones with different PMI, the average values of these tensors can be found in the thesis of A. Angermuller (2021)[17]. Four simulations were done for the following PMI: 3 years, 13 years, 50 years, and archeologic older than 500 years. The following Figure (13) summarizes the results found.

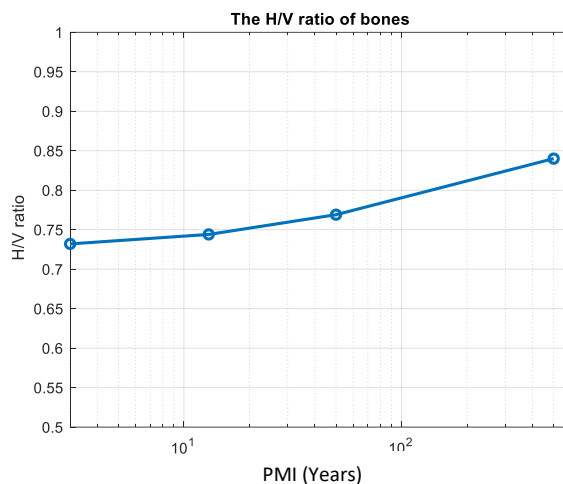


Figure 13: $\chi = H/V$ variation as a function of the PMI of the bone.

The ellipticity χ for different bones varies between 0.74 and 0.84 ($0.74 < \chi_{bone} < 0.84$). One can see that χ increases as a function of PMI. Since there are no two identical values for two different PMI, this means that the ellipticity could be an indicator of the PMI of a bone. The increasing nature of χ could mean that the rigidity of the bones increases with the PMI. This last remark is based on the observation between softwood and hardwood, for which ellipticity χ increases as the rigidity of the material increases.

In this section, the ability of the ellipticity of the Rayleigh waves as a characterization parameter is discussed, for example in the case of distinguishing between hardwood and softwood, or giving an idea of the stiffness of a bone (in relation to the PMI). In these cases, we did not compare the values with a theoretical model, which allows us to extract more useful information rather than just comparing values between them. These results are preliminary and only obtained on a simulated signal, so experimental validation will be an essential step.

5. Conclusion

In this work, a minimal contact method has been presented for the non-destructive evaluation of cultural heritage materials. When the surface of the object is only accessible, surface acoustic waves such as Rayleigh waves are used as the main propagating wave. The extraction of the signals is performed by a 3D Laser vibrometer allowing the measurement of the three components of the particle displacement generated by the propagating wave. In the case of Rayleigh wave, the particle motion has a characteristic elliptical shape, characterized by two parameters, the ellipticity χ and the orientation θ of the elliptical motion. The theoretical expression of χ as a function of the mechanical properties (E, ν) of an isotropic medium is well established. The theoretical study of the relative error showed that χ is very sensitive to measurement errors. This cannot be avoided if the traditional H/V spectral ratio method is used, since this last cannot distinguish between the desired Rayleigh wave and the other propagating waves or the ambient noise. To overcome this problem, a method based on the Hermitian filters is

presented, allowing the extraction of the eigenpolarization of a bivariant signal. The estimation of the polarization properties is carried out using the variation of the gain of the filters as a function of χ and θ given at the output of the bank of Hermitian filters. This method is tested and validated using three types of signals: a synthetic perfect signal, a signal extracted from a simulation of Rayleigh wave propagating on a block of aluminum and an experimental signal extracted using the 3D vibrometer from a Rayleigh wave propagating on the surface of an aluminum block. The obtained results are compared to the theoretical ones, a good agreement is to be noticed. This highlights the capacity of the bank of Hermitian filters to estimate the polarization properties of Rayleigh waves. The method is also applied to signals from simulations of different materials. The ellipticity of Rayleigh waves propagating on two different species of wood is extracted and compared. These results highlight the capacity of χ to distinguish between the two different species of wood. Propagation on bones with different PMI is also simulated. The ellipticity is estimated, and the results showed that χ increases with the PMI, and it could be used as an indicator for bone characterization. In future work, we will focus on the theoretical model for the orthotropic case, allowing us to extract more useful information about the mechanical constants of the wood or bones, followed by experimental validation.

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