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Electronic system to speckle phenomenon characterization for random movement on fiber optics

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ABSTRACT

Peru is a country located in a telluric area. The early detection of earthquakes will alert the population and avoid human losses. There are different methods to detect it, mainly on mechanical movements and electronic sensors, which are currently used. This article presents the analysis and implementation of a repetitive motion generation and detection system based on the study of the speckle phenomenon through an optical fiber. The analysis is calculated by the technique of averaged difference that allows obtaining the intensity variation of two consecutive frames, as the speckle pattern changes and occupies different positions. Several tests are carried out that show the relationship of the controlled random movement and speckle characteristics obtained, the test system that can be used for the detection of random movements similar to P and S earthquakes waves.

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1. INTRODUCTION

The seismic activity of Peru shows that we live in a zone of high telluric activity. The city of Lima suffered some earthquakes of great magnitude, that have caused great losses according to the report of Morales [1]. In the last 20 years, Peru has been no stranger to earthquakes of great magnitude, which have caused considerable human and material losses, generating a great impact on the health and socioeconomic sectors. The last earthquake of great magnitude occurred on August 15th, 2007, the epicenter was un the city of Pisco - Ica, which had a magnitude of 7.9 on Richter scale and caused considerable damage. According to reports from the INEI Peru [2]. A total of 192,492 houses were damaged in three provinces (Ica, Lima, and Huancavelica), equivalent to 78.10 as shown in Table 1.

Table 1. Impact on housing in affected regions, Pisco Peru earthquake 2007

Region province	Total homes	Total homes with damage	homes with damage (%)
Ica	166,265	134,109	80.66
Lima	62,049	41,454	66.81
Huancavelica	18,170	16,929	93.17
Total	246,484	192,492	78.10

The Geophysical Institute of Peru (IGP) and the National Seismological Center (CENSIS) reported that on June 22, 2021 at 21:54 local time (02:54 GMT) an earthquake of magnitude 6.0 occurred, whose epicenter was located in the Pacific Ocean, 33 kilometers south of the Peruvian capital, being one of the strongest earthquakes recorded in recent years in Lima [3]. Seismicity in the Peruvian territory is due to the process of plate subduction (Nazca and South American plates) and the dynamics of each of the tectonic units present in the interior of the continent [4], the collision of these in turn generate what are called seismic waves. Seismic waves are oscillations (sound waves) emitted after a seismic movement are transmitted throughout the interior of the earth [5]. Two types of internal seismic waves are differentiated: P-waves and S-waves. These waves are reflected, refracted and diffracted in the different discontinuities surfaces [6].

The Geophysical Institute of the National Polytechnic School IG of Ecuador is the main research center for the diagnosis and monitoring of seismic and volcanic hazards. The Geophysical Institute has a real-time active instrumental monitoring program using different sensors and electronic equipment. These include: El Streckeisen (STS-2), which is a three-component broadband frequency sensor that can accurately record changes in ground motion (velocity) in the frequency range 0.01 Hz (1,000 sec.)-50 Hz. These sensors are most often used in passive experiments and can record weak regional earthquake and teleseismic motions, as well as ambient noise. Another of the most sophisticated is the Gu¨ ralp (CMG-3ESP) which is a three-axis (tri-axial) seismometer that is composed of three sensors inside an ultra-light housing, which can measure the north/south, east/west and vertical components of ground motion. This sensor is sensitive to ground vibrations at frequencies in the range of 0.003-50 Hz [7]. Due to this wide response range it is conventionally used in seismic and volcanic observatories [8]. Finally, we have the Sercel (L4C-3D) which is a seismometer that works at a frequency of 1 Hz in 3 components: vertical, horizontal north-south, horizontal east-west with a sensitivity of 171 [V/m/s] and a gain of 32 [7]. To detect telluric movements there are various techniques based on different physical principles such as optical techniques that have many advantages, such as; They are immune to electromagnetic interference, highly flexible, adaptable and highly sensitive. Since optical fiber offers interesting advantages related to phase velocity and have been proposed as an alternative transmission medium to radio systems, there are two types of fibers: single-mode and multi-mode fiber. For long distance sensors, optical amplification is considered to prevent the optical signal quality from deteriorating to levels below the measurement sensitivity [9].

The phenomenon of Speckle has a variety of applications, such as for the design of devices to detect the states of physiological activity or inactivity of people, in a non-intrusive way and without direct contact [10]. In the case of a single-mode fiber, the projection of the beam at the fiber output is a uniform light spot, while for a multimode fiber a grainy light pattern is observed. In the latter, the speckle pattern occurs, which is a random interference phenomenon between propagated modes within the optical fiber [11]. The Speckle phenomenon caused by the refraction of modes in the optical fiber (sensor), is extremely sensitive to external disturbances, being an alternative to be used as a motion detector [12]. In detection technology, particular characteristics of the speckle phenomenon obtained in multi-mode fibers are used and currently there are other commercially available multi-mode optical fibers and other materials such as polymeric optical fiber (POF) with core diameters from 50 um to 3 mm, its advantages are numerous in short distance applications over glass [13]. This paper proposes the analysis of the speckle phenomenon, produced by the vibrations generated in the optical fiber through the study of the characteristics obtained in the video frames acquired via a webcam. The analysis is performed by using algorithms that contain techniques of averaged differences between frames and the characterization of the system by the method of linear regressions. The main theme is to lay the groundwork for an alternative early warning system based on fiber optics to detect the initial movements of telluric phenomena, and to warn the population so that they can be safely located moments before the telluric phenomenon.

2. METHOD

The proposed method consists of three stages. The first is the implementation of the vibration system which allows the generation of controlled repetitive movements allowing to simulate seismic movements. The second stage consists of the adaptation of the optical fiber to a video camera and the capture of the speckle phenomenon in video files and the last stage consists of the analysis of the obtained data and tests with uncontrolled movements.

2.1. Speckle phenomenal

The speckle phenomenon is an optical phenomenon that can occur in two ways: with the formation of the speckle pattern by illuminating a rough surface or with a laser light through a multi-mode fiber optic strand [14]. The latter will be used in this study. Figure 1 shows how the speckle pattern has been obtained through a coherent light beam. Transmitted light with homogeneous distribution are small interfering particles; at a given point, two or more waves can overlap [15]. Coherence between two waves refers to the necessary condition for interference to occur between them [16]. In the case of light waves, this coherence implies that the waves have the same frequency, polarization, initial phase and origin (light source) [16].

Figure 2 shows the structure of the index hopping multimode fiber, it has many propagation modes. The index or the medium where n1 propagates is homogeneous, it is constant, it does not depend on the position. In communications, when propagating a rectangular pulse it will be transported by different modes that have different phase velocities, therefore at the output they will arrive at different times, this rectangular pulse is widened and is known as modal dispersion [17].

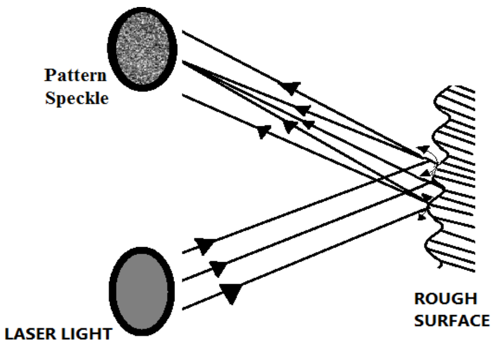

Figure 1. Speckle pattern formation on rough surface [8]

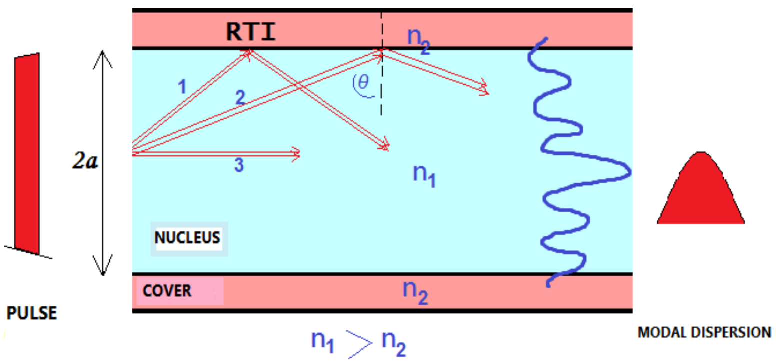

Figure 2. Multimode fiber to index hopping [15]

Multi-mode fiber allows the passage of several light beams, causing interference phenomena. There are two ways to describe the optical modes in a fiber; the first uses geometrical optics ”ray theory” and the second uses electromagnetic wave ”electromagnetic theory”, that is, light is considered as a wave and is also called modal theory [18]. The modal theory describes the behavior of light inside an optical fiber and allows to explain the properties that the ray theory is not able to explain [18]. Modal theory suggests that light can be represented as a plane wave characterized by its direction, amplitude and wavelength. The wavelength of a plane wave is given by (1).

$$\lambda = \frac{c}{f x n} \quad (1)$$

Where:
λ = Wavelength
c = Velocity of light in vacuum
f = Frequency of light
n = Refractive index of the medium

In order for a mode to remain inside the core it must meet a number of boundary conditions, the beta propagation constant (β) must remain between the following values (2) [18].

$$\frac{2\times\pi\times n_2}{\lambda} < \beta < \frac{2\times\pi\times n_1}{\lambda} \quad (2)$$

Where:
λ = Wavelength
β = Propagation constant
n_1 = Nucleus refractive index
n_2 = Refractive index of the cover

The number of modes carried in a multi-mode fiber is determined by (3). Delta which is the relative refractive index difference. Where: N.A. is the numerical aperture, n1 is the refractive index of the core and n_2 is the refractive index of the multimode fiber cladding (4).

$$N.A \approx n\_1 \sqrt{2\Delta} \quad (3)$$

$$\Delta \approx \frac{n_1 - n_2}{n_1} \quad (4)$$

In the same way, any two modes can be interfered with by generating their own interference pattern. In the following expression we consider two different modes. Where the expressions of their electric fields aredescribed by (5) and (6) [12]. Where: $\vec{E}_{0i}$is the amplitude of the wave, r and ϕ respectively denote the radial and azimuthal direction, φ is the propagation constant, z the propagation direction, ω the angular frequency, and t the time. β associates each propagated mode with a random phase. The index i=1 ó 2 [12].

$$\vec{E}_1(r,\phi,z) = \vec{E}_{01}.\exp[j(\omega t - \beta_1 z + \phi_1)] \quad (5)$$

$$\vec{E}_2(r,\phi,z) = \vec{E}_{02}.\exp[j(\omega t - \beta_2 z + \phi_2)] \quad (6)$$

2.2. Implementation of the vibration system

The speckle phenomenon is linked to the coherence of light. It was with the invention of the laser in 1960, when research began systematic both in the description and explanation of its origin, as in its multiple properties, which has allowed to derive innumerable metrological applications, regardless of its consideration as a source of noise [19]. Although in most applications of optical networks, switching techniques and a type of tunable lasers that are capable of reaching high switching speeds [20], are used, this article is based on the analysisof the speckle phenomenon, which does not It requires techniques or sophisticated equipment for its study. Figure 3 shows how a common 650 nm laser is used, regulated with a supply voltage of 3.8 V and 4 V. The different voltages will regulate the light intensity and the current in the diode.

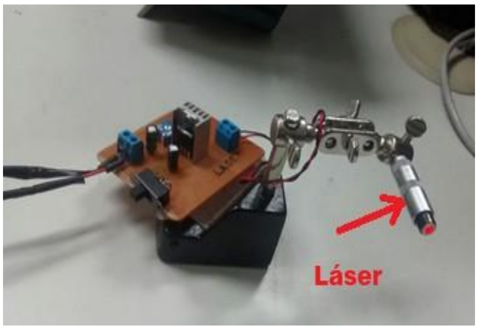

Figure 3. Light source is emitted by a 650 nm laser diode

Table 2 shows the characteristics of the devices and equipment used in this study. The fundamental requirement for this circuit is to provide a signal luminous with a continuous and stable power. In this way, power fluctuations recorded at the other end of the fiber only the attenuation of the light within the plastic fiber optic [21].

The laser light is conducted through an optical fiber (POF) of 250 µm diameter. The POF is subjected to different vibrations controlled through an acoustic system and a wave generator. These vibrations generate movement and variations in the projection of light on the camera. To reduce sensitivity to disturbances from external factors and to support sufficient modes for this application, was chosen the fiber from 250 µm [22]. Adaptation of the optical fiber to the video camera. Figure 4 shows a direct adaptation of the light in the POF, where the laser emission beam falls on theextreme point of the POF in order to obtain a good coupling of light and good quality of speckle pattern [13].

Table 2. Main specifications of the seismograph implementation of the seismograph

Device	Specifications
POF	Diameter: 250 µm m_1=1,492 m_2=1,402 Attenuation: <50 dB/Km Numerical apertura: 0.5-0.66 Category IEC: A4 Coating: plastic bandwidth: 11 GB/s wavelength: 650 nm
Laser Beam	Current: 3 mA Operating voltage: 3 V-5 V DC Video
VGA camera	Format: 24 BIT RGB a 30 fps Focus range: 5 cm to infinity Interface: USB 2.0 Compatible.
Frequency generator	Frequency range: 1 µ Hz to 100 MHz Output impedance:50 Ω Input impedance:10 kΩ output amplitude:10 Vpp Modelo: Tektronix AFG3102

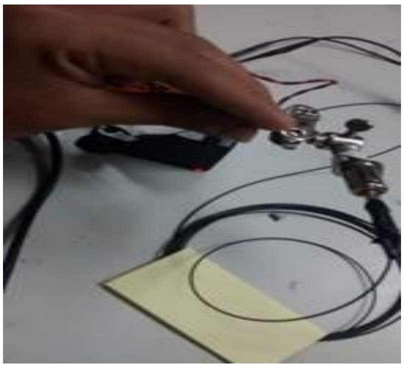

Figure 4. Incidence of laser emission on the POF end point

It was provided, through the light emitted by a 650 nm laser diode that is powered by an appropriate voltage and current. For illumination, we have used a laser emitting red light at 650 nm, which is powered with a voltage of 5.25 volts, at that potential we would be using approximately 0.45 mA, so that the diode emits laser light at its maximum capacity and does not break the threshold current of 0.5mA. To detect vibrations of different intensities, it is necessary to find a suitable fiber, which is versatile for demonstrations and practical purposes, the optical fiber of 0.5 mm or 0.25 mm in diameter will be used because it is more adaptable, the fiber is plastic because it is less rigid than glass, previously a brief study of the properties and characteristics in this case multimode was made. Plastic fibers (POF) of 250 or 1000 µm diameter support enough modes to use this application, for our case we use 250 µm optical fibers. It can be performed with a commercial webcam for capturing the speckle pattern images, but to obtain a better capture it is recommended a CCD camera with CCTV placam, with 700 tvl resolution, 1⁄3-inch Sharp with chip lens mount that allows to modify the saturation characteristics in order to improve the captures to 30 images per second, which the detection frequency can reach up to about 10 Hz and for higher frequencies, higher speed cameras are needed.

2.3. Data collection

Figure 5 shows the working scheme for the development of the seismic movement tests. A laser pointer is adapted to a POF, the emitted light is received by a video camera. The vibrations are generated by a system based on the use of a loudspeaker and a Tektronix controlled signal generator (AFG 3102) for frequency and amplitude variation. The video obtained from the movement generated in the fiber and the appearance of the speckle phenomenon is captured and stored in a computer.

Figure 5. Schematic diagram of the general system

3. RESULTS AND DISCUSSION

3.1. Visual pattern analysis

Figure 6 shows the block diagram of the acquired video analysis system. Speckle Photography is based on the experience of Burch and Tokarsky and their applications. This experience is based on the determination of the displacement of speckles by means of the optical processing of the negative of a film in which, by double exposure, the speckle patterns are recorded before and after a deformation of the object [23].

The obtained video is divided into several RGB images for pre-processing and conditioning. The speckle pattern is more sensitive as the number of modes increases, where the fiber is subjected to external vibration. Therefore, the higher the activity, the higher the variation and consequently, the higher the intensity value [12]. In the acquisition of the video frames and for the analysis of the speckle phenomenon, the technique of absolute difference is used, where the difference between two consecutive frames is calculated and an absolute value of the difference obtained between the images is obtained. Additionally, in order to attenuate the noise effect, an averaging filter is used between a number of samples N obtained [13]. Figure 7 shows the image of the acquisition of the video frame in RGB, the number of frames will depend on the elapsed time of the video and the fps of the camera; in this case, it is a TAKY S-502 WEBCAM camera of 30 fps.

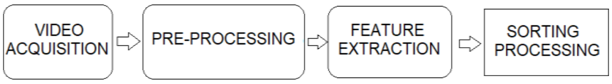

Figure 6. System block diagram

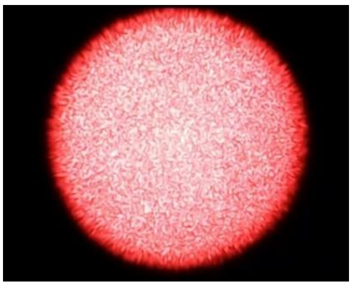

Figure 7. Acquisition of the video frame

In order to reduce the amount of data and to obtain better processing, the image is processing, the RGB image is changed to grayscale, as shown in Figure 8. Grayscale, as shown in Figure 8. The movement generates changes, images that show the interference between the propagation modes and the exchange of energy between them by disturbing the fiber [24].

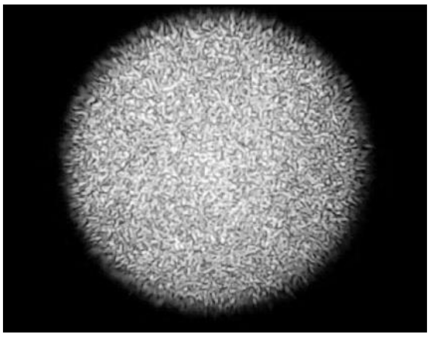

Figure 8. Grayscale frame

Figure 9 shows the division of the frames that compose the video acquisition. To determine the variation of the frames, the images are taken pair by pair, image 1 with image 2, image 3 with image 4, so consecutively up to image N; relatively image 1, 2, 3, ..., N sare represented by F 1, F 2, F 3, ..., F (N). The analysis consists in determining the average value of the variation existing between two consecutive frames to obtain the behavior of the pattern.

Figure 10 shows the intensity variation between 2 consecutive frames (averaged differences technique), as the pattern changes and occupies different positions, constructing point by point the original signal (blue signal) and the signal of the mean filter with an order of N=30 (red signal) to attenuate the noise of theoriginal signal.

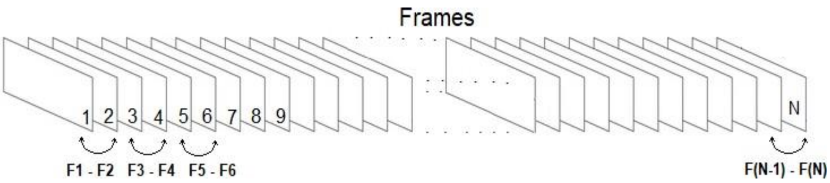

Figure 9. The sum of absolute differences (SAD)

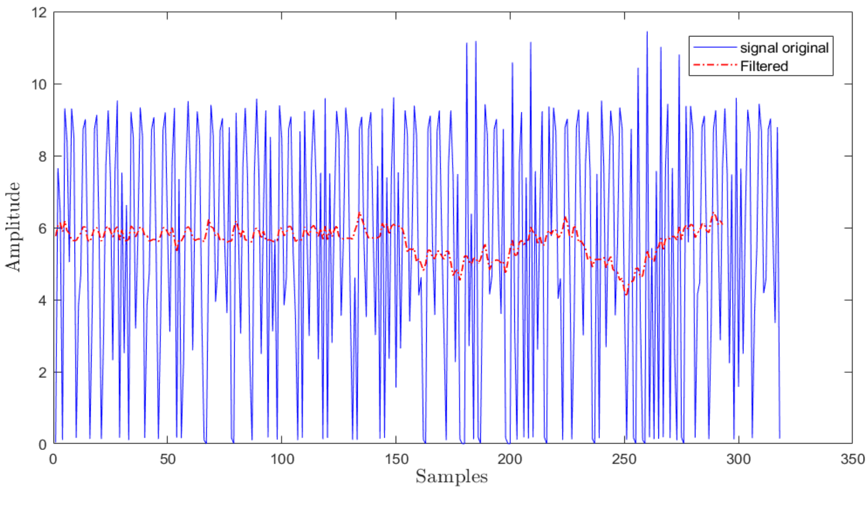

Figure 10. Original signal and middle filter signal

Figure 11 shows the signals obtained by the mean filter from the video generated in the lab tests for the from the video generated in the laboratory tests for a controlled controlled motion with frequencies of 1 Hz, 2 Hz, 3 Hz, and 4 Hz. The result of this analysis shows a variation amplitude of the median filter due to increased frequency activity and excitation of the frequency and laser excitation at a supply voltage of 4.4 V [25].

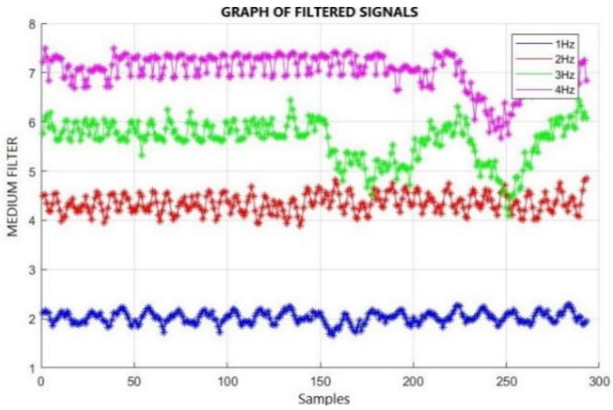

Figure 11. Filtered signals

System characterization was developed using an approximation of second order equation such as (7). Where: Y is the mean value, f is the frequency, and a, b, c are the coefficients. Figure 12 shows the curve fit obtained with the processed data for a 3.8V voltage using (7). For which the coefficients take the following values, $a = 0.345, b = 1.325$ y $c = 0.077$.

$$Y = a + bf + cf^2 \tag{7}$$

Figure 13 shows a better fit of the processed data to the curve for a supply voltage of of the laser of 4 V, using (7), the values of the coefficients obtained are as follows: $a = 0.176, b = 2.141$ y $c = 0.107$. This analysis is performed in order to obtain the characteristic curve of the system. A better adjustment is observed for the curve with 4 voltage sources. This curve allows us to know the behavior of the system under different movements variation such as uncontrolled motion, building, structure vibration or also telluric movements.

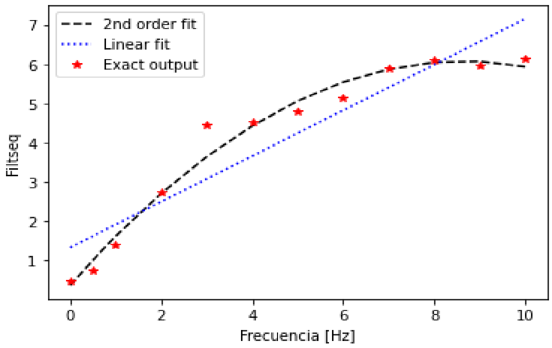

Figure 12. Approximation of the second-order transfer function at 3.8 V voltage

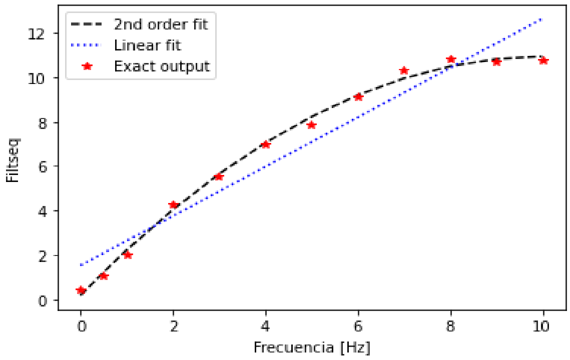

Figure 13. Approximation of the second-order transfer function at 4 V voltage

4. SYSTEM EVALUATION TEST FOR UNCONTROLLED MOVEMENTS

Figure 14 shows the flowchart of the algorithm implemented for the determination of a motion and the estimation of the frequency range of action. The process starts with the acquisition of video frames to determine the average value of the variation between two consecutive video frames, then the absolute values of the variation of the video frame is calculated also, and to attenuate the noise of the original signal, a median filter is used. The average values are obtained from the analysis of the images, these values allow to describes the behavior of the system, (7). Consequently, the movement that produced the speckle phenomenon in the fiber optic can be determined in frequency values *f*. To obtain this frequency of the random movement, roots of a quadratic equation is used (8).

$$f = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (8)$$

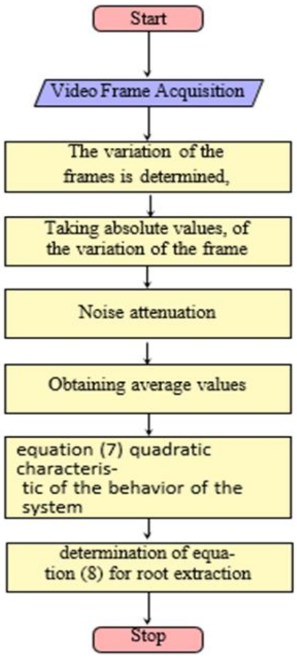

Figure 14. Flowchart of the algorithm implemented for detection and determination of a motion

Figure 15 shows the signal obtained by the median filter for the uncontrolled motion analysis of the uncontrolled motion. The signal is divided into 3 ranges P, Q, and R, from which it is possible to estimate the frequency that generated the random motion. To calculate the frequency of each range, quadratic (7) and roots formula (8) are used.

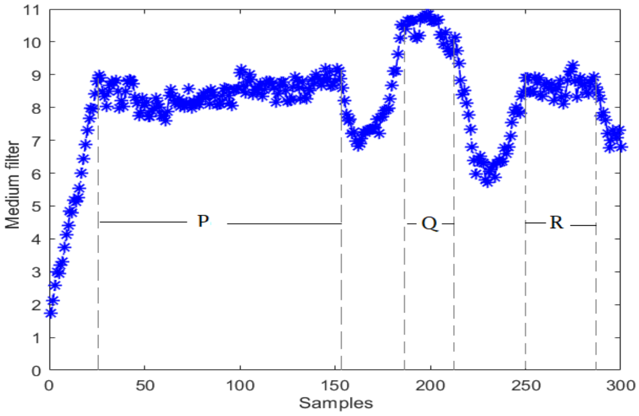

Figure 15. Signal with random motion and P, Q, and R ranges

Table 3 shows the results obtained for the ranges P, Q, and R. Product of the application of (8), 2 roots f1 and f2 were obtained, according to the characteristics of the system the values in the range of analysis of our system were considered, therefore the first range R of motion was generated with a frequency ≈5.8 Hz, the second range Q of motion was generated with a frequency 8.2 Hz and the third range R of motionwas generated with a frequency 5.7 Hz, in this first test the system can be used for motion and random wavedetection.

Table 3. Frequencies obtained in the random motion generated for each range

Frequency range	P	Q	R
f_1	14.22	11.85	14.30
f_2	5.78	8.16	5.71

5. CONCLUSION

The article presents a prototype of a motion detection system based on the speckle phenomenon. The analysis performed for different motions has allowed obtaining an equation that describes the behavior of the phenomenon in the implemented system. Tests were carried out with random controlled movements, identifying three ranges P, Q, and R, for which 3 different frequencies representative of these ranges were estimated. The results obtained in the operation of the system, motivate us to continue a second stage that allows the detection of telluric movements, in which the elaboration of a functional prototype validated with professionalsystems of analysis of telluric movements will be considered.

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REFERENCES

[1] N. Morales-Soto and C. Zavala, "Earthquakes in Peru's central coast: could Lima be the scene of a future disaster? (in Spanish: Terremotos En El Litoral Central Del Perú: Podría Ser Lima El Escenario De Un Futuro Desastre?)," *Revista Perú Med Exp Salud Pública*, vol. 25, no. 2, pp. 217–224, 2008.
[2] C. Bambarén and M. del S. Alatrista, "Estimación del impacto socioeconómico del terremoto en Pisco en el sector salud peruano.," *Rev Med Hered*, vol. 20, no. 2, pp. 89–96, 2009, [Online]. Available: http://www.scielo.org.pe/scielo.php?pid=S1018-130X2009000200006&script=sci_arttext&tlng=pt.
[3] Instituto Geofísico del Perú., "Peru earthquake: 6.0 magnitude quake hits Lima and central coast with no reported casualties - BBC news (in Spanish)," *BBC News Mundo*, 2021. https://www.bbc.com/mundo/noticias-america-latina-57576883. (accessed Sep. 03, 2021).
[4] H. Tavera, I. B. Esquia, C. Condori, M. Ordaz, A. Zevallos, and O. Ishizawa, "Re-evaluation of probabilistic seismic hazard for Peru (in Spanish: Re-evaluación del peligro sísmico probabilístico para el Perú)," *Repositorio institucional - Instituto Geofísico del Perú*, p. 91, 2014, doi: 10.13140/RG.2.2.29589.01769.
[5] G. Arguello, "Qué son las ondas sísmicas?," *blogcires.mx*, 2011. https://blogcires.mx/2014/06/13/que-son-las-ondas-sismica/.
[6] D. Sánchez, R. Howard, and G. Tobón, "Ondas sísmicas," *Angewandte Chemie International Edition, 6(11), 951–952.*, 2016. https://post.geoxnet.com/glossary/ondas-sismicas/ (accessed Sep. 03, 2021).
[7] "Streckeisen STS-2 broadband sensor | PASSCAL Instrument Center," *Passcal.Nmt.Edu*. http://www.passcal.nmt.edu/content/instrumentation/sensors/broadband-sensors/sts-2-bb-sensor%5Cnpapers2://publication/uuid/26B205BD-45A9-40A8-887F-46ACF11AB65B (accessed Sep. 03, 2021).
[8] Guralp, "Operators guide-Guralp 3ESP Compact," *Guralp*, 2016. https://www.guralp.com/documents/MAN-C3E-0001.pdf.
[9] T. Coelho, E. Melão, A. Bessa, D. Coelho, M. Lamin, and M. J. Pontes, "Numerical analysis of remote optical fiber sensors systems with raman optical amplification," *IEEE Latin America Transactions*, vol. 18, no. 06, pp. 1085–1092, Jun. 2020, doi: 10.1109/TLA.2020.9099686.
[10] L. Rodriguez Cobo, M. M. L. Barbosa, J. M. L. Higuera, and A. R. Cuevas, "Dispositivo de detección de actividad/inactividad fisiológica basado en fibra óptica," 2017.
[11] L. Rodriguez-Cobo, M. Lomer, and J. M. Lopez-Higuera, "Fiber specklegram-multiplexed sensor," *Journal of Lightwave Technology*, vol. 33, no. 12, pp. 2591–2597, Jun. 2015, doi: 10.1109/JLT.2014.2364318.
[12] J. R. A. Santamaría, "Estudio de patrones de speckle aplicados a la medida de desplazamiento y posición," 2013. https://repositorio.unican.es/xmlui/handle/10902/1818.
[13] M. Lomer, "Speckle phenomenon in optical fibers and its applications in sensors (in Spanish: Estudio de patrones de speckle aplicados a la medida de desplazamiento y posición)," *Tecnia*, vol. 22, no. 2, pp. 5–16, Dec. 2012, doi: 10.21754/tecnia.v22i2.76.
[14] L. Rodriguez-Cobo, M. Lomer, C. Galindez, and J. M. Lopez-Higuera, "Speckle characterization in multimode fibers for sensing applications," in *Speckle 2012: V International Conference on Speckle Metrology*, Sep. 2012, vol. 8413, p. 84131R, doi: 10.1117/12.978217.
[15] "Fenómeno speckle en fibra multimodo y aplicaciones," *yumpu.com*. https://www.yumpu.com/es/document /read/20354211/fenomeno-speckle-en-fibra-multimodo-y-aplicaciones (accessed Sep. 04, 2021).
[16] L. R. Palomera, "Generación de máscaras para procesado de speckle a alta velocidad aplicado a la detección de ultrasonidos," 2017, [Online]. Available: https://repositorio.unican.es/xmlui/handle/10902/12583.
[17] D. D. I. A.-PUCP, "Coloquio de Física - El fenómeno speckle en fibras ópticas y sus aplicaciones | Educast PUCP." http://educast.pucp.edu.pe/video/1373 (accessed Sep. 04, 2021).

[18] I. H. Madrazo, “Estudio de patrones de Speckle obtenidos por fibras ópticas y sus aplicaciones,” 2013. https://repositorio.unican.es/xmlui/handle/10902/1857.

[19] A. Mira-Agúdelo, “Estudio de fenómenos dinámicos de la óptica del ojo humano,” Universidad de Murcia, 2010.

[20] R. Ma *et al.*, “Wavelength-dependent speckle multiplexing for imaging through opacity,” *Optics and Lasers in Engineering*, vol. 141, p. 106567, Jun. 2021, doi: 10.1016/j.optlaseng.2021.106567.

[21] E. H. Bonifacio Güere, “Sensor de temperatura usando fibra óptica de plástico para uso en transformadores de potencia,” 2013.

[22] J. Sotelo, “ Plastic optical fibers (in Spanish: Las fibras ópticas de plástico),” *Electrónica*, vol. 22, pp. 24–30, 2008.

[23] R. Henao, “Estudio de técnicas speckle opto-digitales,” Universidad Nacional de La Plata, 1997.

[24] L. C. Gutiérrez *et al.*, “Fiber specklegram sensor analysis by digital image processing,” *Revista de la Academia Colombiana de Ciencias Exactas, Fisicas y Naturales*, vol. 42, no. 163, pp. 182–188, Jun. 2018, doi: 10.18257/raccefyn.608.

[25] I. Lujo, P. Klokoč, T. Komljenović, and Z. Šipuš, “Measuring structural vibrations with a multimode fiber optical sensor,” in *Conference Proceedings - ICECom 2007, 19th International Conference on Applied Electromagnetics and Communications*, 2007, pp. 1–4, doi: 10.1109/ICECOM.2007.4544476.

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