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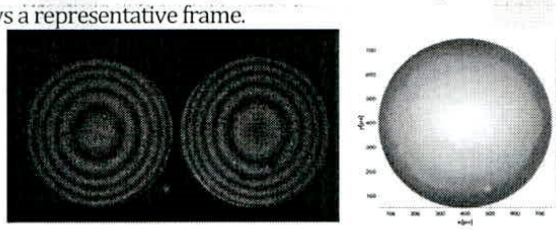
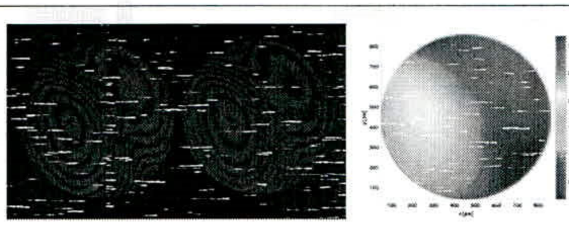
placed on a cover-slip, for this case it was necessary to wait for the flow to stabilize, the parallel patterns show the deformation generated on the original pattern (see Figure 4 (a)). In Figure 4(b) the unwrapped phase is shown. Figure 5 shows the case of an oil drop, placed by the same procedure on a cover-slip. Figure 5 (a) shows the parallel patterns obtained in a single capture of the camera and in Fig. 5(b) we present the phase map; in this case, it can be seen that the oil introduces a larger phase difference because its refractive index is greater than that of the water, for this reason, the frequency of the fringes is greater. In these cases, the relative phase shift calculated by the algorithm is 75.31 degrees. The patterns with this symmetry allow the study of spherical surfaces and lenses, to validate it, a lens with a focal distance f = 30 mm was placed in one of the MZI arms and its corresponding adjustments were made [22-24,32]. The results obtained are shown in Fig. 6. Due to the change in the size of the patterns, small adjustments were made in the zoom focus of the CMOS camera and the angles of the polarizers. Figure 6(a) shows the obtained parallel patterns in Fig. 6(b) we present the recovered phase map. It can be seen that the phase introduced by the sample has small irregularities due the low quality of the tested lens.

With the purpose of showing the capability of the optical system to process dynamics events, the dynamic phase evolution of water moving for gravity on a microscope slide is showed in Fig. 7. It is important to clarify that the results are obtained using an optical table without pneumatic suspension and the used polarized array is formed by recycled polarized film placed at arbitrary angles, which presents the advantage of not using micro-polarized array. These results show that dynamic phase objects can be analyzed with the proposed optical system. Figure 7(a) shows a representative frame of the temporal evolution of parallel interferograms (Visualization 1). In Visualization 2 is possible to see the temporal evolution of the phase map, Fig. 7(b) shows a representative frame.



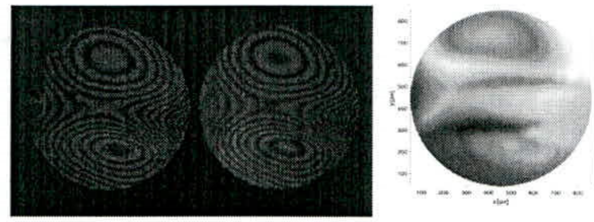
(a) (b)

Fig. 3. Typical interferogram. (a) Parallel interferogramas. (b) Phase map.



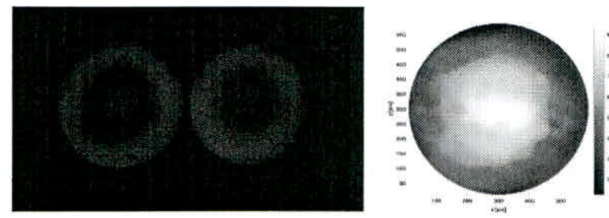
(a) (b)

Fig. 4. Water drop. (a) Parallel interferograms. (b) Phase map.



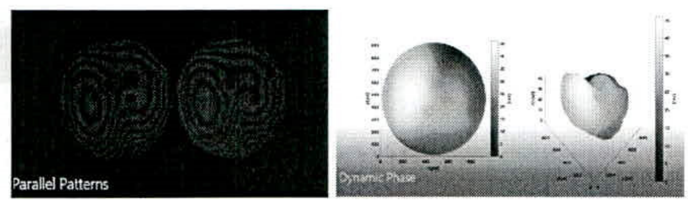
(a) (b)

Fig. 5. Oil drop. (a) Parallel interferograms. (b) Phase map.



(a) (b)

Fig. 6. Lens. (a) Parallel interferograms. (b) Phase map. Relative shift: 31.57 degrees.



(a) (b)

Fig. 7. Dynamic phase object. (a) Parallel interferograms (Visualization 1). (b) Optical phase of water fluid (Visualization 2).

4.1 Spiral and fork fringes

In previous reports [49], it has been shown that patterns can be generated with spiral symmetries without using a Bessel beam. In the results presented in Figure 8, the spirals that are generated when a phase step is introduced obstructing the half of the beam in one of the arms of the MZI. The differences between Figure 8(a) and 8(b) are due to the inclination of the phase-step with respect to the optical axis. These experimental results show that, when tilting the phase step, spirals within the two arms are generated, as shown in Figure 8(a), and with one arm, as shown in Figure 8(b). Fig. 8(a) shown the case of topological charge of two, and Fig. 8(b) can be associated with a topological charge of one, in both case is shown that also have Fork fringes, which is useful if they are to be used as optical traps, since these Fork Fringes represent an optical vortex in the optical phase of the wavefront.

The interferograms with radial symmetry allow to easily generate this type of spiral fringes, which can be applied in other areas as optical traps, these results are useful to know the sign of the phase [49-50].

systems is to recover the optical phase to be able to calculate characteristics of the incident wavefront or physical properties of transparent samples. The main purpose of this work is to measure variations of phase maps of transparent objects using two interference patterns with unknown phase shift in one shot. The configuration is based on a radial shear polarized Mach-Zehnder interferometer (MZI) that generates a base pattern with known polarization properties [30-31] and a cyclic path interferometer for replication purposes. Experimental results of different static transparent samples, such as an oil drop and a lens are obtained. For the study of dynamic events, experimental results of temporal variations of a water drop placed on a slide moving for gravity are presented.

2. INTERFEROMETRIC SYSTEM DESIGN AND BASIC PRINCIPLE

Figure 1 shows the diagram of the polarized parallel phase shifting interferometer. A spatially filtered polarized plane wavefront linearly polarized at 45 deg is coming from a laser operating at 532 nm. This wavefront is incident at the polarizing beam splitter (PBS) of a Mach-Zehnder interferometer (MZI). In each arm of the interferometer a Galilean´s telescope (Gt_1 and Gt_2) is placed. In one arm, the telescope is inverted with respect to the other [39] to reduce the size of the incident beam.The expanded and contracted polarized wavefronts recombine at the beam splitter (BS) to give radially sheared wavefronts with orthogonal circular polarizations (pattern base, $P_b(x,y)$). The $P_b(x,y)$ enters to the cyclic trajectory system where the incident pattern is divided in amplitude, (a) a pattern is reflected and follows the M_3-M_4-BS trajectory and emerges from the system, and (b) the other pattern is transmitted following the M_4-M_3-BS trajectory and emerges from the system, both patterns enter the PA to generate patterns with visible fringes and arbitrary phase shifts.

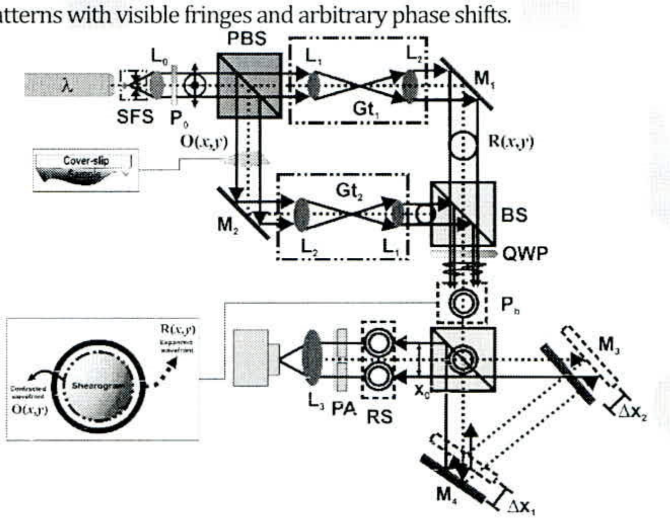


Fig. 1. Parallel phase shifting radial shear interferometer. SFS: Spatial Filtering system. L_0: Collimating lens. P_0: Polarizer. PBS: Polarizer beam splitter. Gt_1, Gt_2: Galilean telescope. L_1, L_2. Telescope lenses. M: Mirrors. BS: Beam splitter. QWP: Quarter Wave Plate. x_0: Beam separation. Mirror displacements:Δx_1, Δx_2. RS: Replication stage. PA: Polarizing array. L_3: imaging lens. O(x,y): Sample. R(x,y): Reference beam. P_b: pattern base

2.1. Radial shear phase shifting interferometry

In the first stage of the implemented system, the polarizing beam splitter transmits the horizontally polarized beam and reflects the vertically polarized beam. The separated beams recombine at the output and pass through the quarter-wave plate (QWP) placed at 45 degrees with respect to the axial axis. The radially sheared wavefronts have opposite circular polarization and its beam sections are $O(x,y)=circ[\rho/M_a]\cdot\exp\{i\phi(x/M_a,y/M_a)\}$ and $R(x,y)=circ[\rho]\cdot\exp\{i\phi(x,y)\}$ [38-39]. The amplitude $P_b(x,y)$ of the output of MZI is given by

$$P_b(x,y)=J_L\cdot O(x,y)+J_R\cdot R(x,y) \qquad (1)$$

where $\rho=\sqrt{x^2+y^2}$ and $M_a=1/R$ denotes the relative magnification of the pupils and J_L y J_R the matrix of circular polarizations to left and right respectively. Figure 2 shows the stages of generation of parallel interferograms where at the first stage, the system does not generate an interference pattern, this is observed in figure 2(a). In order to observe an interferogram, it is necessary to place a linear polarizer to verify that the two beams interfere, see Fig. 2(b). This is because the beams have cross-circular polarizations, which, when interfered, generate a constant intensity field that does not have a fringe pattern [30-31], this can be seen in equation (1), $|P_b(x,y)|^2=cte$. However, this pattern maintains the polarization properties required to generate phase shifts by placing a linear polarizer. Thus, by placing the auxiliary polarizer and rotating it at any angle ψ, an interference pattern can be observed maintaining a constant amplitude modulation [31]. This is, when each field is observed through a linear polarizing filter, whose transmission axis is at angle ψ, the new polarization states are:

$$B(x,y)=P_\psi\cdot\left[\frac{1}{\sqrt{2}}\begin{pmatrix}1\\ i\end{pmatrix}\cdot O(x,y)+\frac{1}{\sqrt{2}}\begin{pmatrix}1\\ -i\end{pmatrix}\cdot R(x,y)\right], \qquad (2)$$

where P_ψ is the matrix of the linear polarizer with axis of transmission at angle ψ, given by

$$P_\psi=\begin{pmatrix}\cos^2\psi & \sin\psi\cos\psi\\ \sin\psi\cos\psi & \sin^2\psi\end{pmatrix}, \qquad (3)$$

the irradiance distribution of an interferogram obtained by MZI with magnification M_a can be expressed as:

$$I(x,y)=a+b+2\sqrt{ab}\cos[2\cdot\psi-\Delta\phi(x,y)] \qquad (4)$$

where a and b, correspond to the irradiance of the object and the reference beam respectively, and $\Delta\phi(x,y)$ is the phase difference between these beams, $\Delta\phi(x,y)=\phi(x,y)-\phi(x/M_a,y/M_a)$. The term $2\cdot\psi$ is the phase shift (ξ) introduced for the auxiliary polarizer. The pattern base $P_b(x,y)$ enters a cyclic trajectory system that does not operate as an interferometer, instead, it is used to generate two replicas of the incident $P_b(x,y)$, as shown in fig. 2(c). In order to observe the two interferograms it is necessary to place an auxiliary polarizer as shown in fig. 2(d). The cyclic path system allows to separate the replicas a distance (x_0) by moving the mirror distances Δx_1, Δx_2, see Fig. 2(e). To align the patterns in the *xy* axis, it is necessary to introduce tilt in the mirrors M_3-M_4 of the system as shown in Fig. 2(f). At this stage, we can generate two replicas that propagate collinearly, and therefore do not distort from other aberrations due to the replication system, as it would be the case diffractive elements or holographic masks [30-31]. In the replication stage (RS), the two generated patterns by the cyclic path system pass through the polarizers array (PA), which is formed by linear polarizers placed at arbitrary angles and allows to us to generate parallel interferograms

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6.3 Disclosures

The authors declare no conflicts of interest.

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8. JUSTIFICACIÓN:

Pago de artículo en revista de riguroso Arbitraje e Indexada en el JCR. El trabajo es una colaboración con la UPB y la BUA en donde contribuye con los indicadores de la calidad de calidad en investigación y en docencia con la permanencia de los CA consolidados.titulo "Parallel phase shifting radial shear interferometry with complex friges and unknown shift". Revista Applied Optics, Primer Cuartil, IF:1.9. Pair USA.

9. Clave (Rec. Mat.)	10. Partida (Progr. Y Pres.)	11. Cantidad	12. Unidad de Medida	13. Concepto	14. Especificaciones Técnicas	15. Costo Unitario Aproximado	16. Subtotal
664	33501	1	Pago	Pago por publicación	El Invoice con las especificaciones para el pago se tendrá hasta que el artículo entre a la etapa de producción. Actualmente está aceptado. OSA	990 UDS	990 dólares 18,000.00
					ir al Banco		$ -
							$ -
							$ -
							$ -
							$ -
							$ -
							$ -
							$ -
					38970.10		$ -
					− 18 000		$ -
					20 970.10		$ -
							$ -

RECIBIDO 24 FEB 2020 TULANCINGO DPTO. DE RECURSOS MATERIALES Y SERVICIOS GENERALES

RECIBIDO 11 FEB 2012 TULANCINGO DPTO. DE RECURSOS MATERIALES Y SERVICIOS

AUTORIZACIÓN DE PROGRAMACIÓN Y PRESUPUESTO				22. OBSERVACIONES:
17. Total del Gasto:	18. Máximo Autorizado:	19. Proyecto:	20. Fuente de financiamiento:	El monto de la publicación es de 1980USD de los cuáles la UT de Xicotepec pondrá el 50% de este monto ya que la publicación está en la colaboración con ellos. El monto se deberá actualizar eb el momento del pago
$ -		40	Federal	
			Estatal	
			IP	
21. FIRMA DE AUTORIZACIÓN:	L.C. Liliana Reyes Kanhan			

23. NOMBRE Y FIRMA DE ENCARGADA DE ADMINISTRACIÓN Y FINANZAS:	24. NOMBRE Y FIRMA DEL RECTOR:
Mtra. Oris Estela Vargas García	Mtro. José Antonio Zamora Guido

25. NOMBRE Y FIRMAS DE CONFORMIDAD Y FECHA:

NOTA:

En caso de ser <u>monto mayores de 300 veces la UMA</u> se deberá de verificar el procedimiento de adjudicación: DIRECTA, INVITACIÓN O LICITACIÓN, dependiendo de ello será el tiempo de entrega, conforme lo estipula la Ley en la materia, y el área usuario deberá requisitar el anexo técnico.

Cerrar Guardar Imprimir

BBVA

Fecha y hora de consulta	25/02/2020 2:10:15 PM	Contrato	00088633
		Nombre del Cliente	UNIVERSIDAD TECNOLOGICA DE TULANCINGO

BBVA Net Cash - Pagos internacionales

Operación autorizada

Datos del firmante

Usuario:	ADMIN1	**Poder:**	100%

Datos de la operación

Tipo de operación:	Pago Internacional	**Importe de la operación:**	20,934.84 MXP
Descripción:	OSA	**Fecha proceso:**	26/02/2020
Cuenta de retiro:	0114614704	**Cuenta de depósito:**	2086784287
Titular cuenta de retiro:	UNIVERSIDAD TECNOLOG ICA DE TULANCINGO	**Nombre beneficiario:**	OPTICAL SOCIETY OF AMERICA
Banco destino		**Datos del tercero**	
Código:	//FW026009593	**Dirección:**	1501 PENNSYLVANIA AVE NW
Banco:	BANK OF AMERICA, NA	**Ciudad:**	WASHINGTON DC 2
Dirección:	969 GALLATIN PIKE S	**País:**	USA
Instrumento de seguridad:	ASD 1856803838		
Importe a cargar a la cuenta:	20,934.84 MXP	**Importe de la divisa a enviar:**	1,084.29 USD
Tipo de Cambio a la Venta:	19.3074		
Referencia:	PAGO PARCIAL DEL INVOICE 1259210 AUTOR ID 973880 M ANUSCRIPT ID 385632PARALLEL PHASE SHIFTING RADIAL SHEAR INTERFEROMETRY WITH COMPLEX FRING		

Datos de confirmación de la transferencia

Folio del módulo de extranjero:	5360987	**Folio único:**	I6F2202002251410120002720045

Estado operación

Porcentaje firmado:	100%	**Estado:**	Operado

Detalle de firmas

Acción	Usuario	Porcentaje aportado	Fecha
CREO	ADMIN1	--- %	25/02/2020
FIRMO	ADMIN1	100 %	25/02/2020