Measuring Phase with Stokes Measurements

Angela Dudley¹, Giovanni Milione², Robert Alfano² and Andrew Forbes¹.

¹ CSIR National Laser Centre, Pretoria, South Africa.
² Institute for Ultrafast Spectroscopy and Lasers, Physics Department, City College of New York, 160 Convent Ave., New York, NY 10031 USA.

Presented at
59th Annual SAIP Conference
University of Johannesburg, South Africa
8 July 2013
Merely measuring the intensity of a beam does not provide the full information.
Numerous methods to extract the phase exist…
But they are often over-complicated and expensive

\[ \frac{d\phi(x,y)}{dx} = \frac{\Delta x}{f} \]
The phase difference between the horizontal and vertical components of a field can be extracted via Stokes polarimetry.

\[
S_0(r, \phi) = |U_{\leftrightarrow}(r, \phi)|^2 + |U_{\uparrow}(r, \phi)|^2 = I_0^\circ + I_90^\circ \\
S_1(r, \phi) = |U_{\leftrightarrow}(r, \phi)|^2 - |U_{\uparrow}(r, \phi)|^2 = I_0^\circ - I_90^\circ \\
S_2(r, \phi) = 2|U_{\leftrightarrow}(r, \phi)||U_{\uparrow}(r, \phi)|\cos(\delta(r, \phi)) = I_{45^\circ} - I_{135^\circ} \\
S_3(r, \phi) = 2|U_{\leftrightarrow}(r, \phi)||U_{\uparrow}(r, \phi)|\sin(\delta(r, \phi)) = I_R - I_L
\]

\[
\delta(r, \phi) = \frac{1}{2} \arctan \left( \frac{S_3(r, \phi)}{S_2(r, \phi)} \right)
\]

\[
\ast \quad |U_{\leftrightarrow}(r, \phi)|\hat{x} + |U_{\uparrow}(r, \phi)|\exp(i\delta(r, \phi)) \text{ : Control the phase between } \uparrow \text{ & } \downarrow
\]
Stokes polarimetry involves four separate measurements.

Requirements for a digital adaptation of Stokes polarimetry:

- Independently control the phase between $U$ and $I$
- Adjust the phase between $I$ and $U$ by $\pi/2$
- Measure in an orthogonal basis: $I$ and $U$
Spatial light modulators allow us to alter the phase of an optical field.
We exploit the SLM’s diffraction inefficiency to independently control the phase between orthogonal polarization components.

- Independently control the phase between &
- Adjust the phase between & by \( \pi/2 \)

\[ |U_x(r, \phi)| \hat{x} \]
\[ |U_y(r, \phi)| \hat{y} \exp(i \delta(r, \phi)) \]
\[ |U_x(r, \phi)| \hat{x} \]
\[ |U_y(r, \phi)| \hat{y} \exp(i \pi/2) \]
A polarization grating is a beam-splitter for left- and right-circularly polarized light... allowing two Stokes parameters to be measured simultaneously.

\[ I_R \]

\[ I_L \]

Measure in an orthogonal basis: \( \uparrow \) & \( \downarrow \) \( \leftrightarrow \) OR \( \bigcirc \) & \( \bigcirc \) \( \checkmark \)
Combining these techniques, we can develop an all-digital approach for extracting phase.
Our approach consists of only 3 components: LCD, PG and CCD.

- **CCD**: 1600 x 1200 pixels
- **SH**: 69 x 69 lenslets
The modes that can be measured are endless...

Opt. Express 22(11), 14031-14040 (2014)
The SLM can also mimic free-space propagation

\[ U(r, z) = \mathcal{F}^{-1}[\mathcal{F}[U(r, 0)] \exp(ik_z z)] \]

This allows us to extract the phase of propagating beams in real-time.
This could lead to understanding the dynamics of phase singularities