Tu3.4	SIMPLE MULTIPLEXING SCHEMES FOR SENSOR NETWORKS EXPLOITING LOW COHERENCE INTERFEROMETRY

A.B.L.Ribeiro[1] , T.Y.Liu[2] , Y.J.Rao and D.A.Jackson
Applied Optics Group, Physics Laboratory,
University of Kent, CANTERBURY, Kent. CT2 7NR, UK.

Introduction

Low coherence interferometry offers the possibility of solving the 'powering up' problem associated with all fibre optic interferometric sensors used to measure slowly varying measurands such as temperature or displacement. In a typical system, the remote sensor is illuminated with the output form a source with low temporal coherence and interrogated using a second interferometer which is scanned such that its optical path difference (OPD) is maintained to be exactly equal to that of the sensor. In order that fibre optic sensors can compete with conventional electronic sensors it is desirable to be able to multiplex several sensors. A variety of multiplexing configurations for interferometric sensors exploiting low coherence processing have been developed, which include coherence tuning(1) and time division multiplexing (TDM)(2). Practical difficulties are experienced with both techniques. The main problems with coherence tuning are i) the optical path length of each sensor must be different (incremented by the source coherence length) which imposes restrictions on the sensor designs, particularly in the case for a network of miniature sensors, and ii) very high cross talk levels, as the recovered signal contains both the desired signal for the coherence tuned sensor and uncorrelated optical power from all the other sensors in the network, which inevitably results in very poor S/N ratios. The noise associated with the uncorrelated signals can be eliminated by exploiting TDM; however, as it is necessary to sequentially coherence match the local receiving interferometer (LRI) to each sensor, the technique is difficult to use in practice.

Here we report two novel partially multiplexed configurations where the problems listed above can be solved by fully multiplexing the scanning interferometer and the signal processing unit, whilst at the same time the sensor network is only partially multiplexed.

Configuration (1) Long Rang Tracking

The basic optical configuration for long range tracking is shown in figure 1a. The output beam from a low coherence optical source (LCOS) is first collimated and directed into the transmission Michelson interferometer (TMI). The output signal of this interferometer is then injected into a 50/50 multimode coupler and then used to illuminate the two bulk optic Michelson interferometers acting as sensor simulators.

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[1] INESC - Optoelectronics Group, Rua José Falcão, 110, 4000 PORTO, Portugal.
[2] University College of Swansea, South Wales.

The optical source was a multimode laser diode (Mitsubishi 4406) which had been deliberately overdriven to induce facet damage in order to make it operate as a high intensity low coherence source. The central wavelength (λo) was 787nm. The autocorrelation function of the source shown in Figure 2 was measured by scanning the transmission interferometer. As can be seen from Figure 2 the envelope of the autocorrelation function closely resembles a Gaussian function, the effective coherence length (L_C) was ~13µm. The outputs of each sensor simulator and the (attenuated) PZT1 scan ramp voltage were digitized with a 12 bit A/D converter and a computer program was used to determine the centroids of the scanned interference patterns and the corresponding voltages.

The scanning range of PZT1 in TMI was 200 microns. Unlike serial coherence multiplexing, the operational range of each sensor in this system can be equal to the full range of the scanning interferometer and the range of each sensor is unaffected by the number of sensors in the system. As with all low coherence sensor systems it is necessary to ensure the induced optical path changes in the sensors do not exceed the tracking range of the scanning interferometer. The maximum scanning range for this configuration is limited solely by the tracking element of the TMI, hence very large displacements can be measured. The resolution depends on the accuracy with which the centroid of the correlation function can be determined and the absolute accuracy of the scanning unit.

Configuration (2) Dual source - short range tracking

The optical configuration for short range tracking is shown in figure 1(b) and is similar to that used for long range tracking except now two low coherence sources are used. The intensities of both sources are modulated at ω_1 and ω_2 and the scanning range of PZT1 in the transmission interferometer is now only $\lambda'/2$ where λ' is the wavelength of either source.

Using the demodulation electronics shown in figure 1b both the absolute phase of each sensor simulator can be determined where (ϕ_c - ϕ_2) gives the absolute optical phase modulo 2π and (ϕ_1 - ϕ_2)gives the fringe number. This method of signal processing has been previously demonstrated [3] for a single sensor. The sources used here were Sharp LT023MC multimode lasers with mean wavelengths of 781 and 789nm. The OPD's of the sensor simulators were set in the region of 500µm corresponding to the centre of the 1st coherence valley of the autocorrelation function[4] of both sources, as indicated in figure 3. The maximum tracking range of this approach is set by the effective wavelength, $\lambda_e = \lambda_1\lambda_2/(\lambda_1 - \lambda_2)$ or the coherence length of the source, whichever is the smaller; this also sets the scanning range of each sensor. The accuracy depends on the linearity of the scanning PZT1 and to a small extent the frequency stabilities of the optical sources, as unlike the long range tracking approach, the path imbalance of the system is finite. In figure 4 are shown the output signals from the two sensor simulators in configuration (1) as a function of the drive voltage applied to PZT1. The top traces correspond to the initial OPD's of the simulators and the bottom traces are the output signals produced when the OPD's of the simulators have been changed by an arbitrary amount. A linear relationship was obtained from the positions of the centroids of each trace determined from the known expansion to voltage coefficient of PZT1 and the drive units of each simulator. The resolution was > 50 nm with an operational range of ~200 μm. The data taken with configuration (2) is shown in figure 5. In figure 5(a) the variation of ($\phi_1 - \phi_2$) as the OPD of simulator 1 is varied over its full dynamic range is shown; this data gives the fringe number. The variation of ($\phi_c - \phi_2$) over the same range is shown in figure 5(b); the total number of fringes scanned was 115. These data are combined to obtain the absolute value of the phase of sensor 1. The equivalent displacement resolution was ~1nm and the working range 45μm. Similar data was obtained for sensor 2.

A common advantage of both multiplexing methods is that the optical power is used much more effectively as the optically encoded output signal from each sensor is returned directly to a detector, via an optical fibre rather than back through the fibre network used to distribute the optical power to each sensor. This approach has another significant advantage in that there is virtually no optical cross-talk, unlike systems which are multiplexed using coherence tuning.

Acknowledgements: This work was partially funded by the SERC/DTI Nanotechnology link scheme. A.Ribeiro also acknowledges the financial support of the Optoelectronics Group of INESC, Porto, Portugal and the Treaty of Windsor.

References

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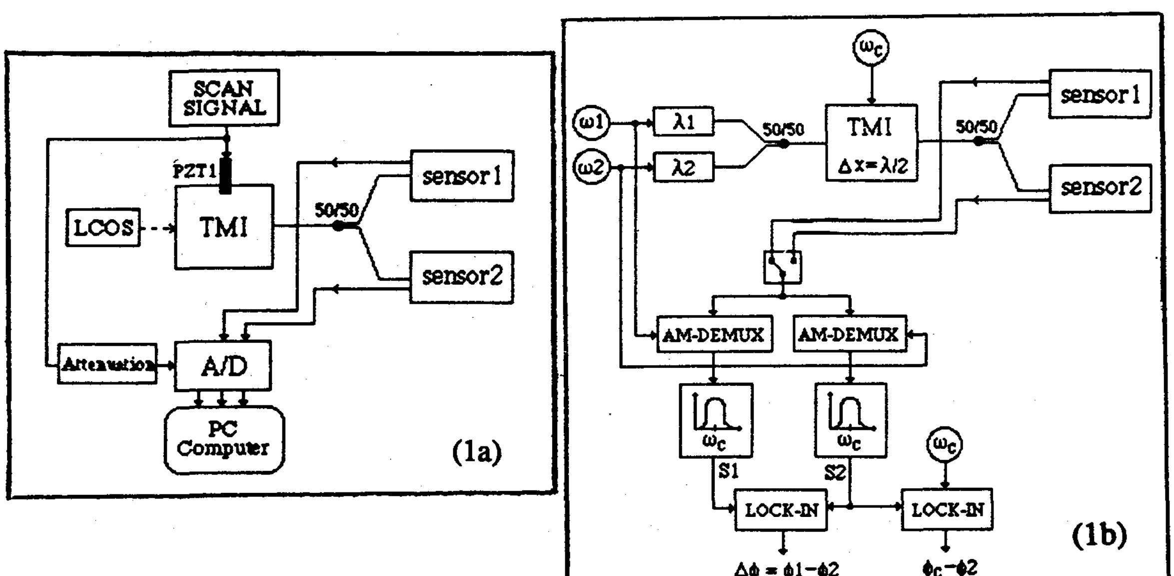

Figure 1. Basic optical layout of the multiplexing sensor network exploiting low coherence interferometry (a) long range tracking configuration and (b) short range tracking configuration.

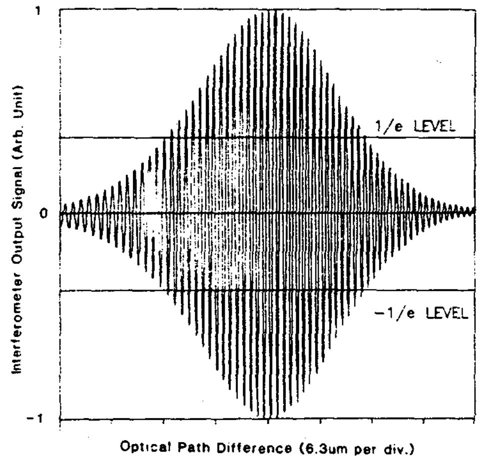

Figure 2. Autocorrelation function of the multimode laser diode (ML4406), with facet damage.

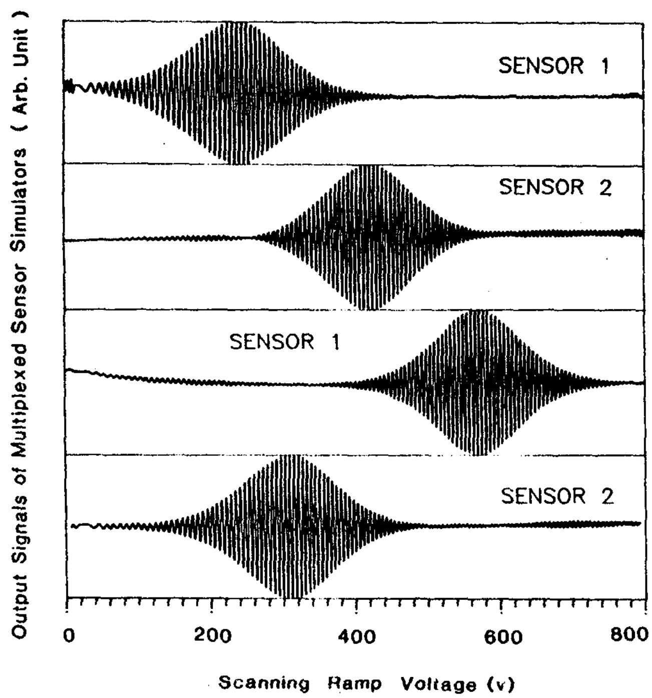

Figure 4. Unprocessed output signals from the sensor simulators (configuration 1), as a function of the voltage applied to PZT1.

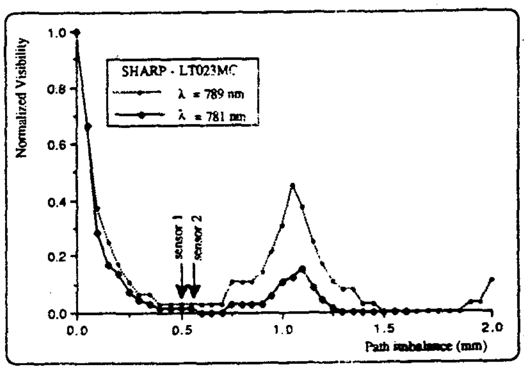

Figure 3. Autocorrelation functions of the Sharp laser diodes. The OPDs of the sensors simulators are also indicated.

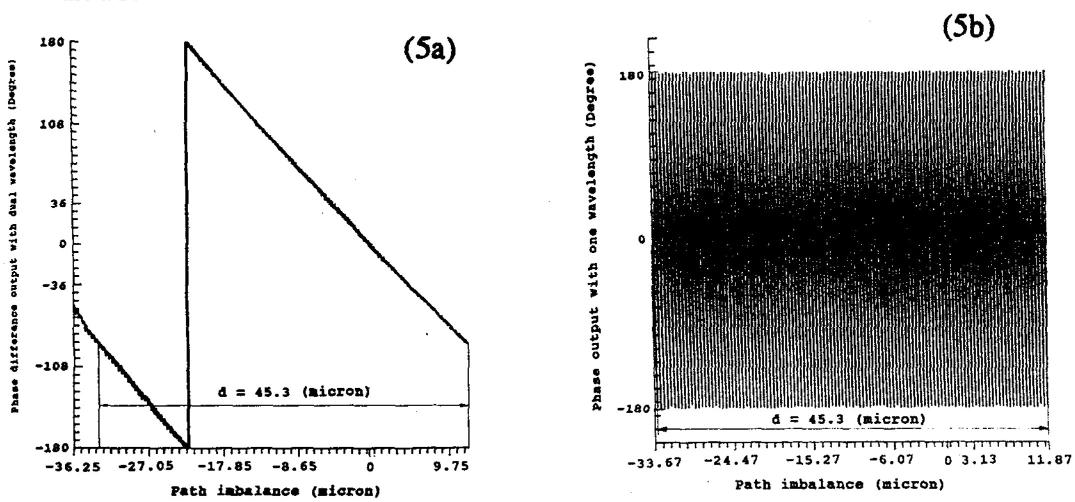

Figure 5. Data recovered from the processing electronics for configuration 2; (a) shows the variation of $\phi_1 - \phi_2$ as the OPD of sensor simulator is varied over the full dynamic range, (b) is the variation of $\phi_c - \phi_2$ over the same range.