Optical force sensor based on multi-mode fibre and MIMO signal processing

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A (2×2) multiple-input multiple-output (MIMO) implementation for signal processing is realized by using lower-order and higher-order fibre mode groups and experimentally explored for fibre optical force sensor applications. We describe the experimental setup utilized for the measurements and confirm a high correlation between an optical fibre sensor measurand and MIMO processed data, for the first time.

1 Introduction

In the field of fibre optic communications spatial division multiplexing (SDM) is currently investigated in order to overcome the capacity limit of common single-mode fibres (SMF) [1]. One approach of SDM utilizes individual transversal modes of multi-mode fibres (MMF) for data transmission. However, due to external perturbations such as bending and elongation of the optical fibre along the optical MMF link and fibre imperfections cross-talk between the transversal modes can occur and, thus, MIMO signal processing has to be applied at the output in order to recover each orthogonal signal at the input [2].

In this paper MIMO signal processing is experimentally explored for optical fibre sensor applications. The experiments are based on a (2×2) MIMO implementation which has been realized by using lower-order and higher-order mode groups of a gradient index (GI)-MMF as separate transmission channels. Cross-talk was obtained between the transmission channels by introducing a defined and repeatable perturbation, i.e. by applying a micro-bender (MB) and different forces (in our case by using different weights). By observing the MIMO layer specific weight-coefficients of the system, the amount of perturbation i.e. the amount of force applied was determined.

2 Experimental set-up

The experimental set-up has already been described in [3] and is illustrated in Fig. 1.

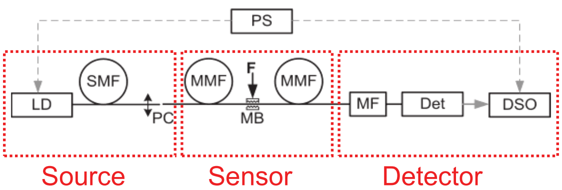

Fig. 1 *Schematic of the experimental set-up for the investigation of the applicability of MIMO signal processing for fibre optic sensor applications [3].*

As indicated in Fig. 1 the experimental set-up established for this investigation consists of a laser-diode (LD) operating at a wavelength of 1327 nm, 1 m SMF followed by the MB containing a 2 m GI-MMF with a subsequent coil of GI-MMF with a length of 1400 m, a 40-GHz detector (Det), a 50-GHz digital sampling oscilloscope (DSO), a pulse generator (PS), a position controller (PC) as well as a spatial mode filter (MF) in front of the detector. The details of the systems are described in [3].

The PC was applied in order to excite different mode-groups by changing the off-set position of the SMF relative to the centre of the GI-MMF (i.e. the optical axis). Fig. 2 displays the measured intensity pattern of the respective mode groups when centric and eccentric light launching conditions are applied.

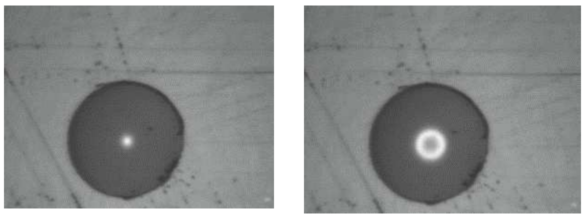

Fig 2 *Measured intensity distribution at the output of the GI-MMF for centric (left) and 16 µm eccentric (right) light coupling conditions.*

The MF only allows light of a certain spatial distribution, i.e. light from the lower-order or higher-order mode-groups, to reach the detector. For the experiments two MB units with five and ten teeth, respectively, were utilized and the force applied to the MB was adjusted by employing high-precision weights.

3 Results

In Figs. 3 and 4 the measured impulse responses are illustrated for a MB unit with ten teeth and 0 gram and 400 gram load, respectively [3].

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According to the results shown there the amplitudes of the peaks, which represent the power carried by individual principal modes, are changing due to the applied force. Moreover, Fig. 5 illustrates the dependence of the MIMO layer-specific weighting factors to different forces (i.e to different loads) for the two MB units. From Fig.5 it is obvious that a high correlation between an optical fibre sensor measurand and MIMO processed data has been confirmed for the first time, to our knowledge. The stronger response of the five teeth MB unit can be explained by higher pressure applied to the GI-MMF by the MB. As the surface area of this MB unit is smaller a higher local pressure is obtained for similar loads.

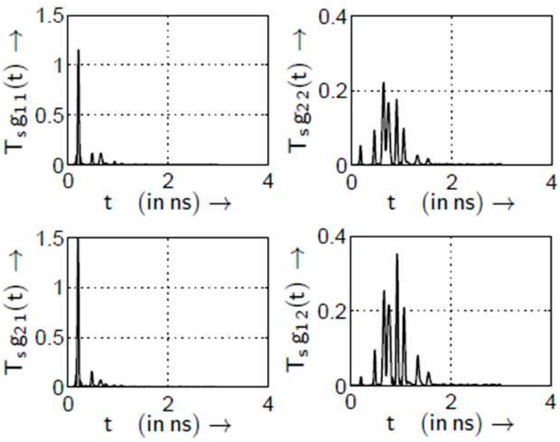

Fig. 3 Measured electrical MIMO impulse responses with respect to the pulse frequency f_T = 1/Ts = 5.12 GHz at 1325 nm operating wavelength (MB unit with ten teeth and 0 gram) [3].

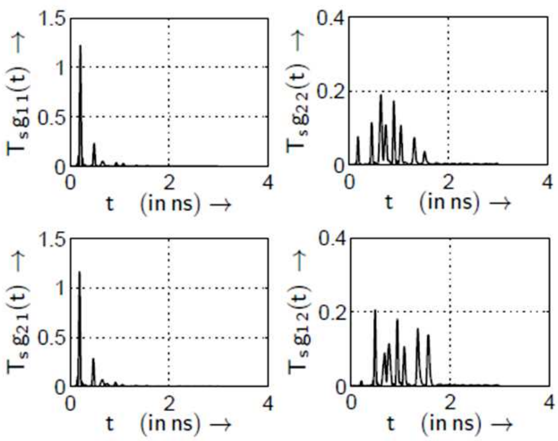

Fig. 4 Measured electrical MIMO impulse responses with respect to the pulse frequency f_T = 1/Ts = 5.12 GHz at 1325 nm operating wavelength (MB unit with ten teeth and 400 gram) [3].

4 Summary

In this paper multiple-input multiple-output (MIMO) signal processing is investigated for fibre optic sensor applications. A (2 × 2) MIMO implementation is realized by using lower-order and higher-order mode groups of a graded-index (GI) multimode fibre (MMF) as separate transmission channels. A micro-bending force sensor is applied in order to introduce cross-talk and, hence, to change the transmission characteristic of the MIMO implementation. Experiments verified a good correlation between the change of the MIMO weight coefficients and the load applied to the sensor and, thus, showed that MIMO signal processing can beneficially be used for fibre optic sensor applications in the future.

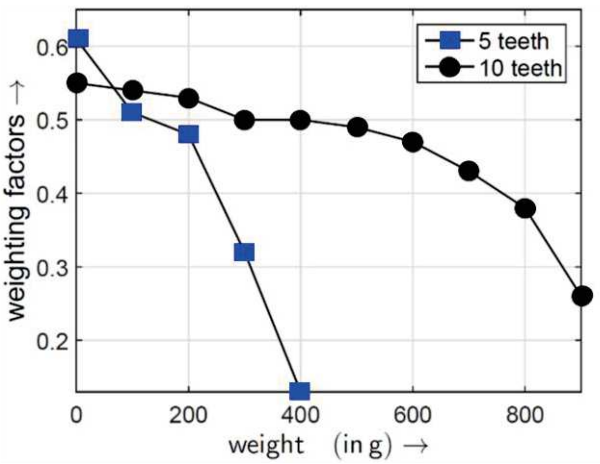

Fig. 5 Sensor dependent changes in the layer-specific weighting factors.

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