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Exploring Geophysical Applications For Distributed Acoustic Sensing (DAS) Using A Flexible Interrogator Research Platform

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Summary

DAS continues to be a promising and cost-effective technology for carbon storage monitoring applications including systems that monitor geological changes using active seismics, and also for passive mode operations, e.g. the monitoring of microseismic activity during CO2 injection. The authors have developed a DAS interrogator research platform that has enabled a better understanding of the critical equipment architecture and experimental factors influencing the collection and analysis of DAS data. The authors plan to test this at different CCS pilot installations. In the future, the performance and functionality of the DAS interrogator research platform will be expanded, and techniques for applying it developed further in order to meet CCS specific needs determined from wider collaboration.

Introduction

Distributed acoustic sensing (DAS) is a technique for measuring seismicity that involves coupling pulses of coherent laser light into an optical fibre, followed by time domain analysis of optical backscatter that naturally occurs as a consequence of inhomogeneities in the glass structure of the fibre itself. The seismicity appears as intensity or phase modulations on the backscatter. It is widely accepted that the main advantage with DAS technology is the ability to monitor relatively large length scales at a lower cost than conventional alternatives. While the existence of the optical backscatter phenomenon behind DAS was demonstrated several decades ago (Healy, 1987), it is only more recent advances in photonic component quality and the increased ubiquity of the fibre optics communications industry that has made DAS an attractive commercial proposition. The development of commercial DAS technology has been driven by the oil and gas industry, which has been attracted by the low investment cost for installing optical cables on linear assets such as pipelines and wells. There have been many successful demonstrations of DAS in oil and gas applications, from downhole fluid flow measurements (Johannessen 2013) to vertical seismic profiling (Wu 2015). In parallel with commercial developments, advances in the underlying measurement technology behind different DAS implementations have been widely reported in the scientific literature (Hartog 2013).

There is now a growing interest from the geophysical community to develop and apply DAS technology for cost sensitive applications, including CCS early warning systems that listen for microseismicity and leakage during and following CO_2 injection (Daley 2013). Comprehensive and open knowledge sharing between geophysicists and technologists is a prerequisite for a successful development of DAS into a useful tool for CCS applications. Such collaborations are necessary for facilitating a mutual understanding of the geophysical measurement problem, the technological choices and consequent trade-offs. As part of such a collaboration, the authors are currently developing a DAS interrogator research platform that can be interchanged between different photonic architectures, each with different performance and function characteristics that may suit contrasting applications. The collaboration also has a strong focus on developing methods and techniques for applying DAS in the field.

DAS photonics and data processing

The measured optical backscatter induced by a coherent laser pulse as it propagates along an optical fibre appears jagged due to the accumulated optical contributions from the local distribution of glass inhomogeneities, with the peaks and troughs modulated by local mechanical and temperature perturbations. Systems based on the analysis of these directly obtained backscatter profiles are known as “amplitude” or “intensity” DAS systems. These systems are the simplest, both with respect to the photonic hardware and the computing power required for data analysis. However, in amplitude DAS systems it is not possible to define a precise gauge length, a term commonly referred to in DAS literature that defines the length of fibre over which optical phase changes are evaluated. As a result, amplitude DAS systems have highly non-linear responses. The magnitude of the instantaneous response also fluctuates strongly along the fibre and with time. Therefore, amplitude-based signals at a given location do not facilitate faithful reconstruction of the incident acoustic waveform. It follows that while amplitude DAS systems are suitable for some applications, particularly those where the incident seismic energies are high, amplitude DAS systems are not suitable for establishing satisfying seismic wave dispersion diagrams and cannot be used to collect stackable datasets in multi-shot seismic experiments. “Phase sensitive” DAS systems on the other hand use one of a wide range of more complex photonic configurations that set out to evaluate the optical phase changes that occur within precisely set gauge lengths along the fibre. Data from phase sensitive DAS systems therefore have strong and highly linear responses to the acoustic waves incident upon the fiber, facilitating the calculation of highly useful dispersion diagrams.

The authors have built and tested a DAS interrogator research platform that can be configured either as an amplitude DAS system, or as one of two phase sensitive configurations that we refer to as “Type A” and “Type B”. We have characterized each system configuration using a fixed length of optical fibre wound on a Piezoelectric transducer (PZT) annulus that can elongate the wound fibre with frequency and amplitude given by an electrical signal generator, see for example figure(Figure 1).

Note that each particular method used for evaluating the optical phase carries its own advantages and disadvantages. For example, when using a Type A DAS system, the phase change over a hardware determined gauge length is recovered by combining optical intensity measurements with simple analytical formulae. Such a simple workflow is ideally suited to long fibre DAS systems and where high laser pulses repetition rates are desired. In contrast, for Type B DAS the gauge length is not fixed by hardware, and can therefore be adjusted during post-processing. However, a drawback is the computationally expensive curve fitting procedure implied in the work flow.

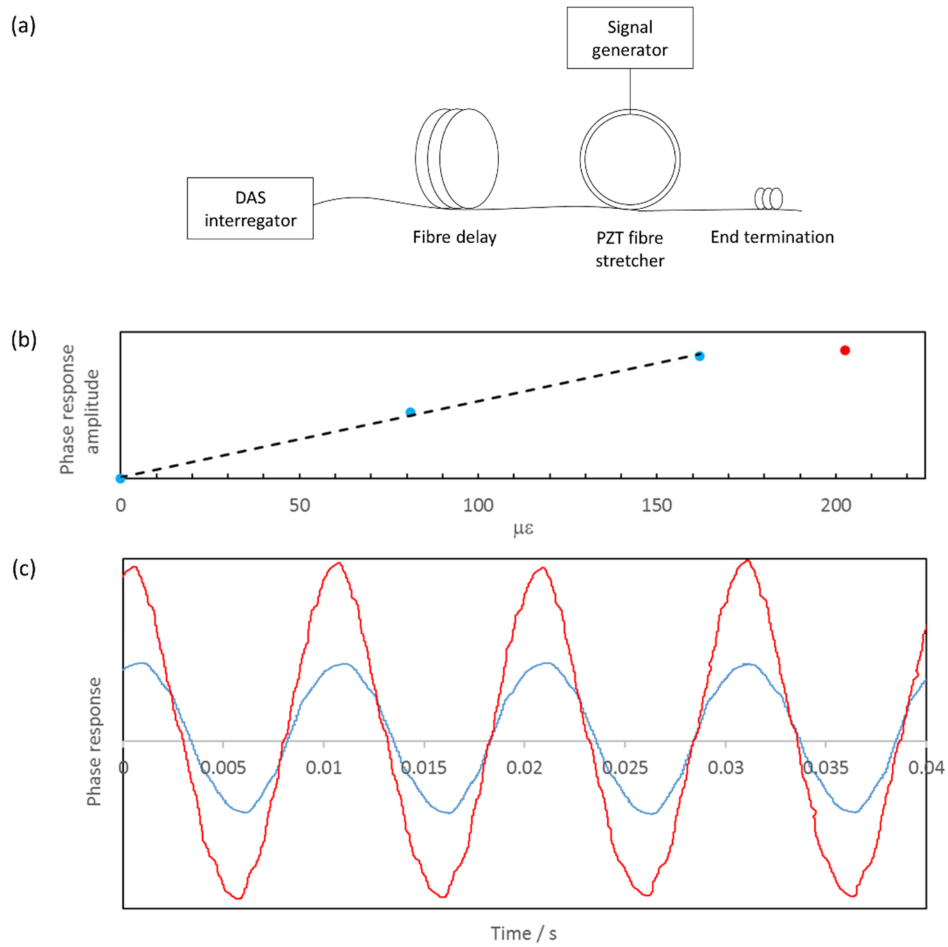

Figure 1 *(a) Setup used for characterising DAS system performance. (b) The phase response of the "Type A" configuration as a function of different maximum applied strains amplitudes (100Hz sine). The gauge length used was ~ 13 m. Note the linear response up to at least ~ 160με.(blue dots), and the nonlinear response for higher strains (red dot). (c) The phase response as a function of time for 100 Hz applied strains with amplitude 81 με, (blue) and 203 με (red). Note the conformation to a smooth sinusoid is less at 203 με, indicating a slightly non-linear response.*

DAS Fibre optic cables

In addition to the interrogation technology itself, the structure and layout of the cable are important factors in determining the performance of DAS technologies. The acoustic performance of sensor cables is dependent on factors such as the cable geometry, dimensions and choice of materials (Hoffman 2015). The insensitivity of conventional 'straight' fibre cables to orthogonally incident waves is well known, with the design and application of helical fibre cable architecture representing an active field of research (Hornman 2017). Another challenge concerns the positional calibration of the fibre optic cable. This uncertainty arises partly because the fibre length most often exceeds the cable length due to cable manufacturing constraints. The placement of the cable may also be only approximately known (e.g. buried cables). Procedural calibration methods include using tapping on the fibre, active acoustic sources (e.g. hammer blows), and freezing techniques (Dean 2016). Conversely, other concepts that involve modification of the fibre to inscribe positional markers directly from the DAS data have received relatively little attention. This is most likely because the production of long marker inscribed fibres is still a challenge.

Conclusions

DAS continues to be a promising and cost-effective technology for carbon storage monitoring applications including systems that monitor geological changes using active seismics, and also for passive mode operations, e.g. the monitoring of microseismic activity during CO_2 injection. The authors have developed a DAS interrogator research platform that has enabled a better understanding of the critical factors influencing the collection and analysis of DAS data. The authors plan to test this at different CCS pilot installations. In the future, the performance and functionality of the DAS interrogator research platform will be expanded, and techniques for applying it developed further in order to meet CCS specific needs determined from wider collaboration.

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