In-field quality control of very high channel count autonomous nodal systems

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Summary

Recent development of light, low-cost autonomous nodes that can be deployed rapidly and in very large numbers has the potential to transform the way seismic data is acquired on land. However, unlike with traditional cabled systems or real-time data transfer nodal systems, very large channel count blind nodal systems present challenges for rapid in-field quality control (QC). Rapid in-field QC is required to (1) enable the identification of faulty equipment, even if rare; (2) identify areas with anomalous noise characteristics in order to inform ongoing operations; (3) rapidly assess operational performance across a large population of devices, and (4) extract practical attributes of survey-wide continuously recorded data. We outline key design principles to address these challenges and show results from a recent field trial during which 50,800 prototype lightweight autonomous nodes were deployed a total of 500,000 times (with a fault rate of only 0.16% per month). We also show examples of how apparently mundane attributes of the continuously recorded data can acquire an unexpected value when acquired at high density over large areas.

Introduction

Recent development of light, low-cost autonomous nodes that can be rapidly and efficiently deployed in very large numbers has the potential to transform the way seismic data is acquired on land (Dean *et al.* 2018, Manning *et al.* 2018, Manning *et al.* 2019). However, unlike with traditional cabled systems or real-time data transfer nodal systems, very large channel count blind nodal systems present challenges for rapid in-field QC. In this paper, we outline key design principles to address these challenges. Our arguments are general, but we refer specifically to the development and 2019 large-scale field trial of 50,000 nimble nodes (Manning *et al* 2018, Nehaid *et al*. 2019), in the context of which we discuss both data attributes and in-field instrument calibration.

Methods and Requirements

For the purposes of this paper, when we refer to QC, we mean the ability to see at a glance how the recording system is performing and the characteristics of the acquired seismic data. In a traditional cabled receiver system, information from each channel is transmitted in real time to a central control center, where operators can rapidly assess the operational status of the spread and view raw seismic data attributes. Recording equipment may also be equipped with self-test functionality or relay wireless status information. By contrast, in order to reduce size and complexity and affordably reach very high channel counts, the lightweight nimble nodal system is designed to be blind and only contain essential components. As a result, the operator is only able to assess data quality when nodes are brought in for harvesting. The system is designed to support channel counts of up to 1 million (Manning *et al*. 2019), and it is important that the throughflow of huge data volumes (each charging and harvesting container can process 20,000 fully depleted 4GB nodes per day) does not delay the presentation of useful data attributes and detection of faulty equipment.

Despite the blind nature of this system, rapid in-field QC of recorded data is still required for the following reasons: (1) to enable the identification of equipment that does not meet acceptance criteria; (2) to identify areas with anomalous noise characteristics in order to inform ongoing operations; (3) to statistically assess operational performance across a large population of devices; and (4) to extract practical attributes of survey-wide continuously recorded data (including data outside shooting times and at very low and very high frequencies, which are often discarded before the production of seismic deliverables).

We argue that any high channel count blind nodal system should observe the following five rules. First, in the absence of costly instrument self-test capability, the recording system should have the ability to rapidly verify instrument response functions during data harvesting. Second, QC attributes must be calculated automatically from the raw, streamed data, without delaying harvesting and regardless of when nodes are loaded; any requirement to pre-sort or pre-process the data rapidly becomes a limiting bottleneck as the number of channels becomes large. Third, the initial identification of suspect nodes must be automatic. Fourth, the number of attributes that operators are required to view manually should be modest, since the presentation of excessive and redundant data can hamper rapid decision making. Fifth, all attributes should be easily cross-referenceable and integrated graphically with external topographic, satellite and cultural data. It is ultimately a data reduction problem: in a future million-channel system, most of the raw data will never be seen by human eyes, so the aim is to find the optimal way to condense its salient parts into a form that can be visualized at a glance by the survey operator. We note that fulfilment of these five criteria for the largest surveys may require a significant investment in the design of field data management infrastructure.

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As Figure 1 shows, attributes from the nimble node system fall into the following categories: “engineering”, i.e. those describing the performance of the equipment itself; “seismic”, i.e. those derived from the recorded seismic data; “operational”, i.e. those measuring the performance of line crews; and “calibration”, i.e. those derived from experimental verification of sensor response functions. Operational data is used to monitor the performance of line crew. Engineering attributes are most useful during system development, but some, such as GNSS fix counts, remain important data quality flags during operations; and others, such as average GNSS position, may be used in processing, for example in the calculation of elevation statics. Seismic attributes are survey-dependent and provide valuable information about ambient noise levels, clipping and coupling. Calibration data can detect drifts in sensor behaviour compared to that measured at manufacturing, and, because it is stored, can be used in processing to fine-tune the compensation for variations in instrument response. Comparison between anomalous seismic attributes and calibration data also enables rapid differentiation between nodes that are broken and those that suffer from poor ground coupling or are planted in noisy locations.

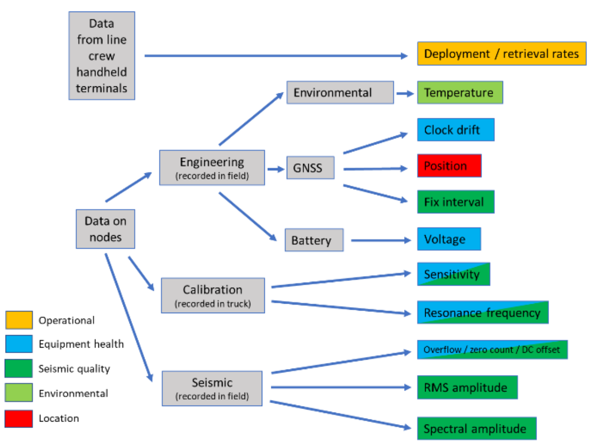

Figure 1: Classes of QC attributes for the nimble node system. All are generated automatically. Engineering and seismic attributes are reported as averages for each hour of operation. Calibrations are performed in the harvesting container up to once per deployment.

Nimble node field trial example

The ultra-high-density field trial described by Nehaid *et al*. (2019) represented the final test of the nimble node system before commercialization and was in part designed to test and develop the ideas discussed in the previous section. A total of 500,000 deployments of 50,800 nodes were completed over 53 days, giving a 12.5x12.5m receiver carpet over an area of approximately 80km^2. Average deployment and retrieval rates were 15 seconds per node. A portable shaker table in the data harvesting container (illustrated in Figure 2) was used to make measurements of each sensor’s response function after deployment (208,000 total). A plot of this data in Figure 3 shows that the sensor response is extremely stable. Figure 4 shows example attribute maps of acquired temperature, GNSS fix interval and seismic RMS data. As part of the automated test sequence, 27 “raw” attributes were calculated using 1-hour chunks of continuously recorded data from each node. A further 32 aggregate metrics were calculated from these raw attributes for each deployment. A selection of these metrics was then used to define a set of automatic nodal rejection criteria. For example, if a majority of 1-hour continuous data segments failed tests on zero frequency amplitudes, numbers of clipped values or consecutive same samples, excessive clock drift or calibration deviations, the node was flagged to the operator during harvesting. Nodes were also flagged if both RMS amplitude and peak frequencies were highly anomalous. Flagged nodes were then manually checked to determine whether to remove them permanently from circulation. This process worked well and there were no problems with data bottlenecks. The simple design of the node meant that reliability was very good, with only 0.16% of the most recent generation developing a fault during each month of operation. An important learning given the consistency of results shown in Figure 3 is that calibration does not need to be performed after every deployment, further improving the efficiency of the turnaround process.

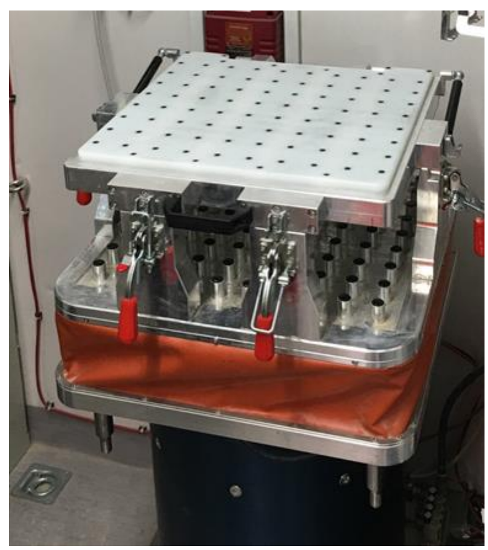

Figure 2: Shaker table used for in-field sensor verification in 2019 nimble node field trial. Table processes one palet of 90 nodes in 2 minutes. Shaking sequence is a combination of a 31.25Hz mono-frequency sweep and a series of broadband pulses. Results are stored in node memory and in system database.

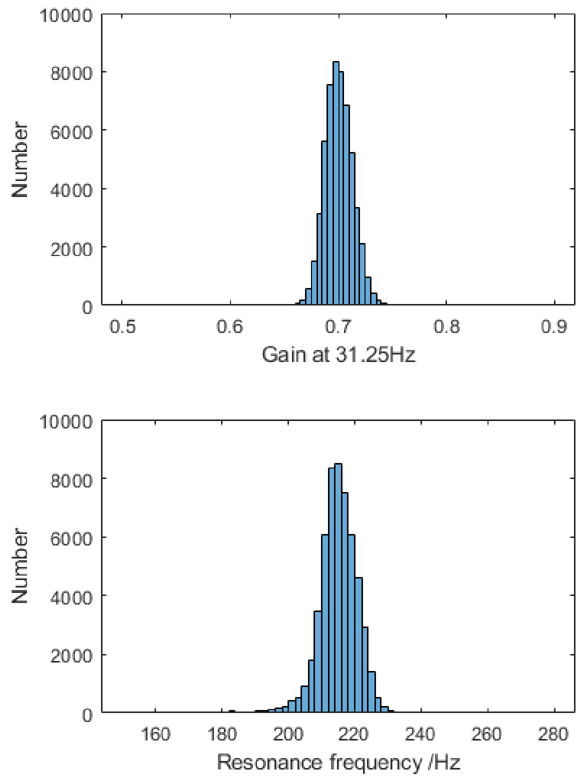

Figure 3: Results of in-field sensor response verification tests of latest generation of nimble nodes using apparatus illustrated in Figure 2. Results show highly stable performance across population and between multiple deployments. Standard deviation in measured gain and resonance frequency is approximately 2% and 3%, respectively, better than typical geophone values.

Beyond the automated detection of suspect nodes, it is worth reflecting on which attributes were most useful for operational decision making as opposed to system development. Temperature and GNSS fix counts provided important information about working conditions and the risk of uncorrected clock drift errors. Anomalous battery decay rates highlighted nodes which systematically struggled to obtain GNSS fixes. Seismic RMS amplitudes track ambient noise levels which, in this survey, were highest at the crests of sand dunes and on windy days. It is worth repeating that it is much easier to make these assessments by cross-referencing points on a map with cultural data than it is to scan through seismic gathers without the same contextual information. These problems worsen as channel counts become ever higher and harvesting becomes less sequential in terms of deployment time and position.

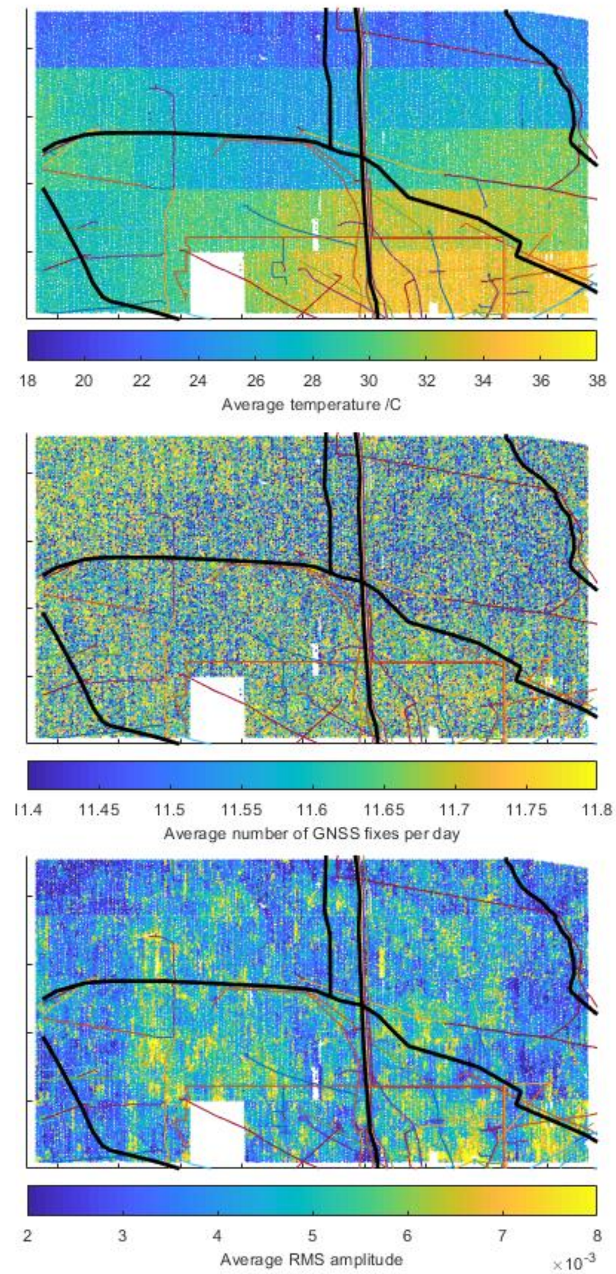

Figure 4: Example attribute maps from 500,000 nimble node locations in 2019 field trial. Black and red lines show infrastructure locations. Temperature map neatly delineates increasing heat as survey progressed. GNSS fix map identifies nodes at risk of uncorrected clock drift errors (very rare in this test). Average RMS amplitudes identify noisy nodes, for example those planted at sand dune crests.

Novel Attributes

Finally, when deployed in dense carpets, some attributes can reveal interesting environmental details. For example, Figure 5 shows that ambient noise levels near the sensor resonance frequency correlate with locations of infrastructure. Single-frequency spectral amplitude maps can also delineate zones of influence of electrical noise sources, pumps and turbines as well as providing more general information about ambient seismic noise characteristics. These auxiliary datasets are acquired at no extra cost and can be used to monitor changing surface conditions during the seismic acquisition period.

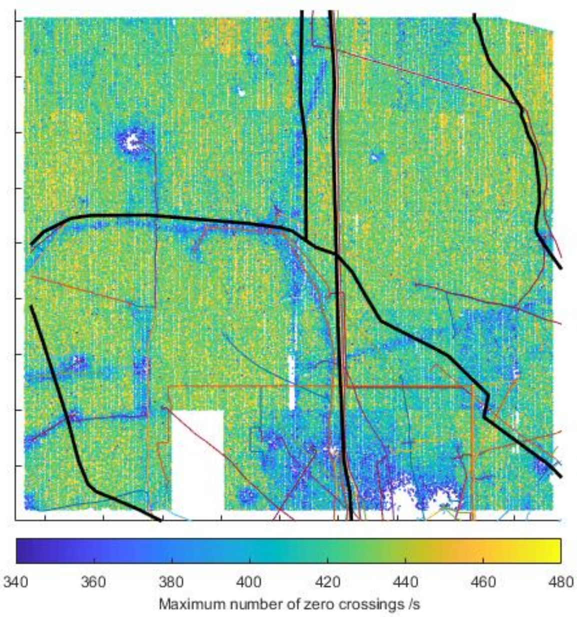

Figure 5: Maximum zero crossing rate (measured in 1-hour windows) in continuous seismic record in 2019 Nimble Node field trial. Note clear delineation of infrastructure. This attribute is sensitive to ambient noise levels near the sensor resonance frequency. Since this part of the data is removed by the system high-cut filter prior to the production of seismic deliverables, these insights would likely be lost if analysis were left until the start of seismic data processing.

Conclusions

While in-field QC of very high channel count blind nodal systems can be challenging, we outline some simple and practical rules for system developers. We show examples from a recent trial of the nimble node system, during which 50,800 nodes were deployed a total of 500,000 times, with only 0.16% developing a fault during each month of operations. Rapid in-field QC methods were essential for demonstrating the strong performance of the prototype system and enabled rapid decision-making during operations.

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