Game-changing nodes enable high-density seismic for any industry

Amine Ourabah[1*], Mike Popham[1] and Chris Einchcomb[1] present a new generation of smaller, lighter nodes making denser seismic accessible to the renewable market.

Introduction

Increased spatial sampling has always been the 'holy grail' for the seismic industry. Since the early 1990s, everyone wanted to acquire denser land seismic surveys, but good reasons were often found to justify why it was not practical – whether it was the sheer volume of data collected, the large quantity of equipment, the limit of seismic resolution, or the exorbitant cost.

When denser sampling finally became affordable in the early 2010s, mainly thanks to the introduction of simultaneous shooting (Howe et al 2008), the ever-increasing sampling started to tremendously benefit subsurface imaging and improve our understanding of the subsurface as a whole. These benefits were demonstrated by the impact of trace density on S/N, resolution, survey geometry, AVO, azimuthal attributes (Ourabah et al, 2015), 4D monitoring (Davies and Ibram, 2015) and more recently on complex inversion and machine learning algorithms (Pu and Zhang, 2018).

The quest for denser surveys kept going until the receiver side of acquisition systems were no longer able to keep up with fast moving autonomous vibroseis. A need arose in the industry for smaller, lighter autonomous receivers that could allow the operator to free both sides of the acquisition system from conventional size and weight constraints, and thereby deliver the densest possible survey for any site at lower cost, lower HSE risk and with minimal environmental footprint.

Scaling down the size and weight of nodes breaks down the cost barrier for not only oil and gas exploration but for other industries using seismic data as their main source of subsurface information. Geothermal and carbon capture, utilization and storage (CCUS) are examples of industries that can benefit greatly from faster, cheaper, denser seismic surveying.

In this article, we outline the motivation behind the invention of the latest STRYDE nodes. We will also discuss how, within a year of entering the market, these nodes have already disrupted the way land seismic is being acquired across many industries, and how by scaling down the size of nodes, high-density seismic acquisition can finally be accessible to all.

High-density seismic: yesterday, today, and tomorrow

Throughout the history of seismic, the development of acquisition systems, survey designs, acquisition methods, complex processing algorithms and powerful computing have all contributed significantly to the dramatic change in the quality of the subsurface image, and will continue to do so. However, we can't miss the fact that big leaps in data quality have occurred when the quantity of measurements per unit of acquisition surface has jumped significantly from one generation to the next (Figure 1).

This factor – which is referred to as the trace density – correlates very well with data quality whether it is for simple stack images (improved S/N) or complex AVO and AVOz attributes (Ourabah et al., 2015). In general, the more complex the attributes sought, the denser the survey needs to be as they often extract trends from less populated sub-groups of the original trace density (Figure 2).

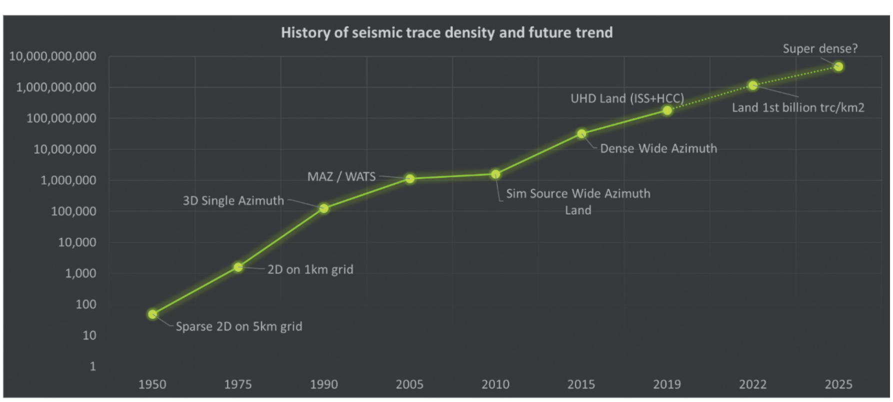

Figure 1 The increase of number of traces per km² since the beginning of seismic acqusition.

[1] STRYDE
[*] Corresponding author, E-mail: amine.ourabah@strydefurther.com
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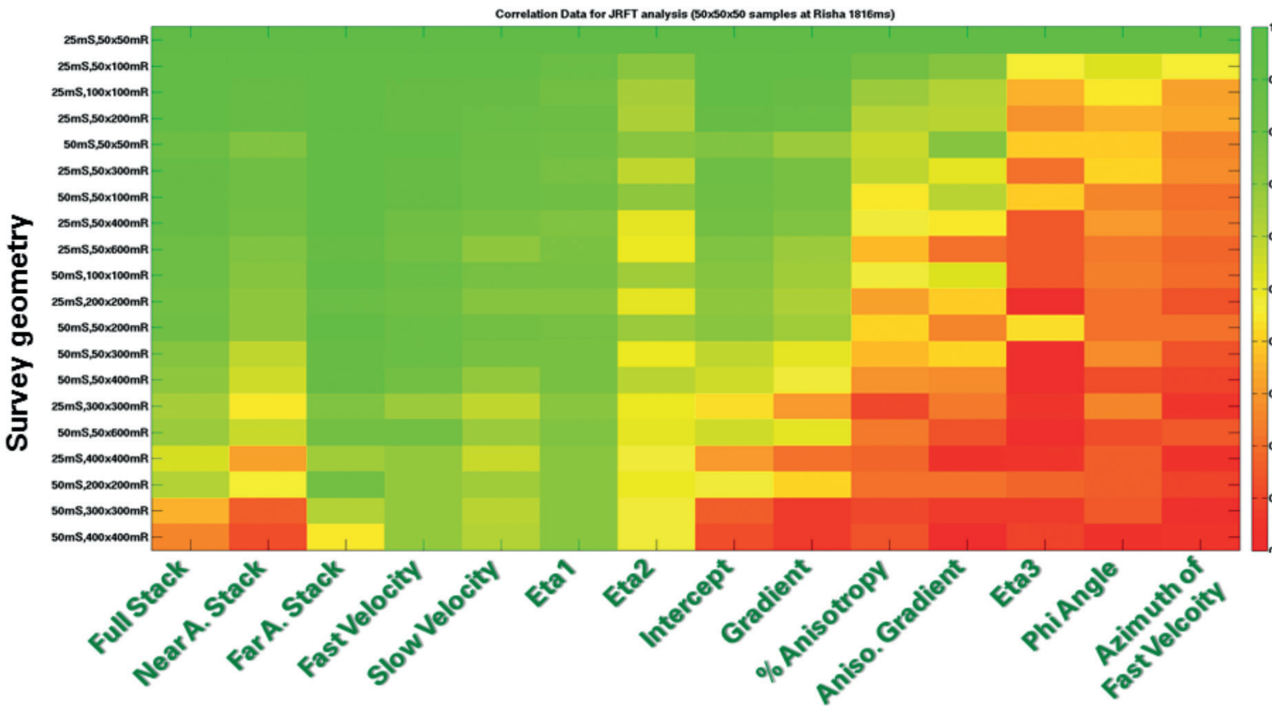

Figure 2 Quality factors of different attributes at a deep horizon in the Risha field vs survey geometries (sorted by trace density) (Ourabah et al, 2015).

If we look at how conventional surveys have evolved to higher density on the source side in the last few decades, we observe that conventional source fleets have been 'distributed' to form much denser single point sources, often shooting simultaneously in an autonomous way to give an unprecedented efficiency compared to vibroseis fleets (Howe et al, 2008).

The receiver side however has lagged behind for a variety of reasons, including: the size and weight of conventional cables and nodes, the cost of procuring sufficient channels and the man power cost to deploy dense channel counts. Spreading the array sensors to independent single point receivers to follow the same trend as the sources could therefore not happen until the sensors were autonomous and nimble enough to allow this explosion of receiver count to reach their full potential, especially when combined with simultaneous source schemes.

Simultaneous source technology is now a widely adopted technology both in marine and land seismic acquisition and one of the major innovations for enabling increased density. This is an example of the industry favouring the *quantity* of measurements over the *quality* of the individual shot gather (Dvorak et al., 2013), confidently relying on the fact that the benefits of increasing trace density outweigh the potential downside of the additional noise added in the form of seismic interference. The same logic is applicable to the receiver side where the legendary

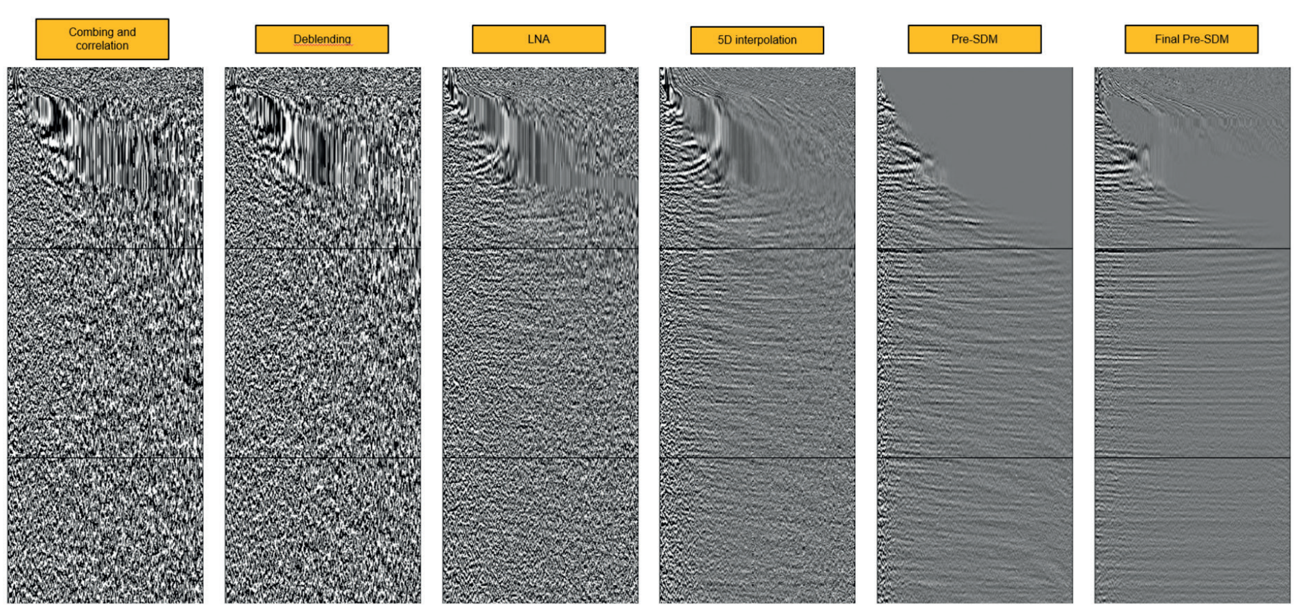

Figure 3 CMP gathers throughout a conventional PSDM processing sequence – large-scale field trial (Ourabah et al, 2020).

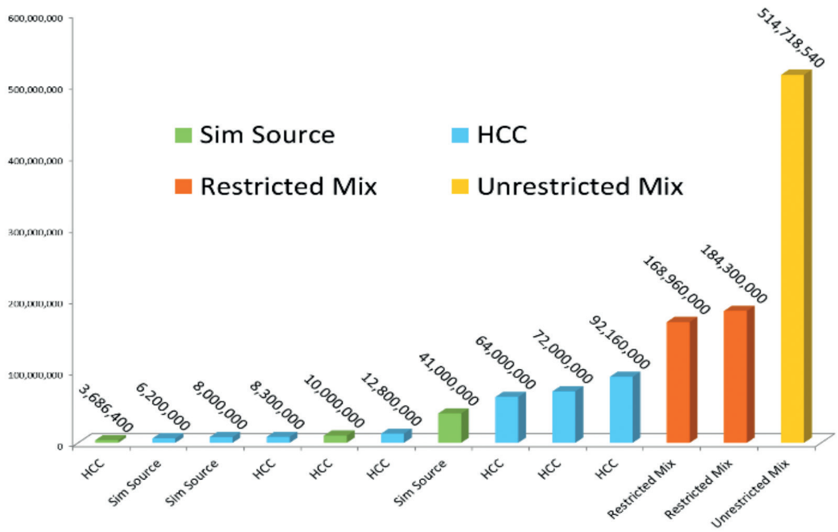

Figure 4 Trace density in traces/km^2 of actual land surveys (excluding yellow bar) acquired in the last 20 years colour coded by the acquisition technology enabling them. Unrestricted mix is a predicted survey density using the best of current source's and receiver's efficiency.

high S/N of big arrays delivering a single trace (often smearing or destroying useful signal) is eventually outweighed by more single sensors distributed across the survey. Single point receivers, although presenting noisier raw data than arrays, are much more truthful to the real seismic wavefield, and deliver a much higher resolution image and better-quality seismic products at the end of the processing sequence, as a result of the higher spatial sampling of both the signal and the noise (Figure 3). The huge redundancy of information, and the ability to process the shear amount of data also play a crucial role in this uplift in data quality (Ourabah et al., 2014; Poulain et al., 2014).

The quest for denser surveys has not stopped. In fact, if we look at some of the densest surveys acquired in the past 20 years (Figure 4), high-density surveys with tens of millions of traces/km^2 were achieved by using either some variation on simultaneous source or a high channel count system, but rarely with the two together.

It was not until recently that we started seeing a mix of these two technologies which is enabling the acquisition of ultra-high-density surveys with trace densities above 100 million traces/km^2. However, we consider these surveys as restricted mix in Figure 4, as either the simultaneous source side was not aggressive enough or the high channel count (HCC) was relatively small or slow.

If a very aggressive simultaneous source scheme is combined with a truly unlimited channel system, it could allow the industry to achieve a new generation of 'super dense' surveys that could even reach beyond a billion traces/km^2. Alternatively, this combination could give total freedom to the operator to increase either the source count or the receiver count or both, depending only on the environment, in order to achieve the desired trace density. This becomes particularly important where source density is restricted, such as in urban areas, around existing infrastructure, or where environmental concerns prevent the use of heavy, intrusive equipment.

A node designed to be radically different

To remove the receiver constraints discussed earlier, nodal systems seemed to be the natural solution. However, existing products still included significant dead weight (heavy batteries, bulky casing) and even the most recent of these systems with smaller build and longer battery life (Dean et al, 2018) were not nimble enough or economically affordable to achieve the vision of an unlimited channel system that will allow the user to efficiently acquire denser seismic surveys in any environment. To answer this specific challenge, BP, in collaboration with Rosneft and Schlumberger, developed a new nodal system revealed to the industry as the 'nimble node' (Manning et al, 2018), the smallest and lightest fully autonomous node for land seismic acquisition (Figure 5). This node has been in development since 2013 and was specifically designed to tackle the most extreme land environments, from hot deserts to freezing Siberian forests and make unlimited channel systems an affordable solution for either high trace density or large coverage seismic surveys.

Figure 5 The nimble node (STRYDE), 150g, 13x4cm.

A small node clearly helps, but it introduces new challenges which need to be considered. For example, how to recharge huge quantities of nodes and download the recorded data efficiently. As such, STRYDE accompanies its nodes with an extremely compact charging and harvesting system. Its building block is an 65x50x20cm 'Nest' capable of charging and harvesting 90 nodes simultaneously. These Nests can either be stacked individually (the STRYDE Nimble system) or installed in racks in 20ft containers capable of holding up to 36 Nests. The efficiency of the container systems (the STRYDE Compact and Pro systems) enables a single operator on shift to turn around as many as 20,000 fully depleted nodes per day.

Several successful field trials in different types of environment were completed prior to the commercialization of this nodal system (Figure 6). A 2D field trial in 2017 in the UAE compared the nimble nodes to three commercial cabled systems and demonstrated the fantastic efficiency of the former vs cabled arrays and cabled single sensors systems (Ourabah et al, 2019); the following trial in 2018 was the first 3D survey with this nodal technology, where it was used in a production survey in Siberia next to a 12-geophone array cable system (Brooks et al, 2018) and demonstrated the efficiency, HSE benefits and robustness of this nodal system in extreme cold and forested areas while producing superior subsurface images. The large-scale 3D field trial completed by ADNOC in the UAE in 2019 was the densest land nodal seismic survey in the world. Acquired in 53 days with 500,000 node deployments, this survey achieved a staggering 184 million traces/ km^2 with half a million node deployments made by a crew of 36 people (Ourabah and Crosby, 2019) (Figure 7).

After these successful trials, Launchpad established STRYDE, an independent start-up that is bringing the 'nimble node technology' to the broader seismic community aiming to make high density seismic affordable to all industries.

The QAQC of a million nodes

Quality control of live systems has been used in the industry since the early 1990s. However, with the increase in trace density, data volume and speed of acquisition, a lot of those QC methods became impractical. Source and receiver systems have also evolved to become much more reliable, which gives more confidence to the operators to ease on the number of parameters and data volume to be checked live. The introduction of blind node systems marks the start of a paradigm shift in field QAQC, as these nodes do not transmit data live to a central unit, and therefore seismic data can only be checked after they are retrieved. However, the "blind" statement is probably misleading as QAQC still happens through the duration of the acquisition every time a batch of nodes is harvested, producing very useful information of the last few days of acquisition and allowing adjustments or mitigation if required. This might sound like a configuration performed too late but in fact, if we consider the speed at which these nodes are mobilized and moved across the survey, a couple of days of QAQC delay is already well ahead of what could have been done with bulkier cable equipment.

If we take the example of the STRYDE nodal system, 27 'raw' attributes are calculated on the fly using the one-hour chunks of continuously harvested data from each node. A further 32 aggregate metrics are calculated for each deployment. A high-value selection of these metrics is then used to define a set of automatic rejection criteria.

For example, if a majority of one-hour continuous data segments failed tests on DC shifts, numbers of clipped values or consecutive same samples, excessive clock drift or calibration deviations, the node is flagged to the operator during harvesting to be rejected. Nodes are also flagged if both RMS amplitude and peak frequencies are highly anomalous. Flagged nodes are then manually checked to determine whether to remove them permanently from circulation. This process worked very well during the large-scale field trial in 2019 where half a million deployments were made with 50,800 nodes (Crosby et al, 2020). Although not in the final manufacturing stage, the nimble nodes showed very good reliability, with only 0.33% of nodes over 53 days developing a fault which was later investigated and associated with fixable firmware issues.

Processing "ultra-high-density" (UHD) data

As often observed in high density seismic processing, once the data handling is managed adequately, the density helps almost all processing methods to be more data driven and achieve better results without compromising primary signal, allowing a 'light handed' approach on the parameterization of filters. Dense surveys also make a very good input to multi-route processing where different stakeholders expect different products from the processing at different points in time.

Figure 6 Deployment of the STRYDE nodes in a Taiga forest (left) and desert environment (right).

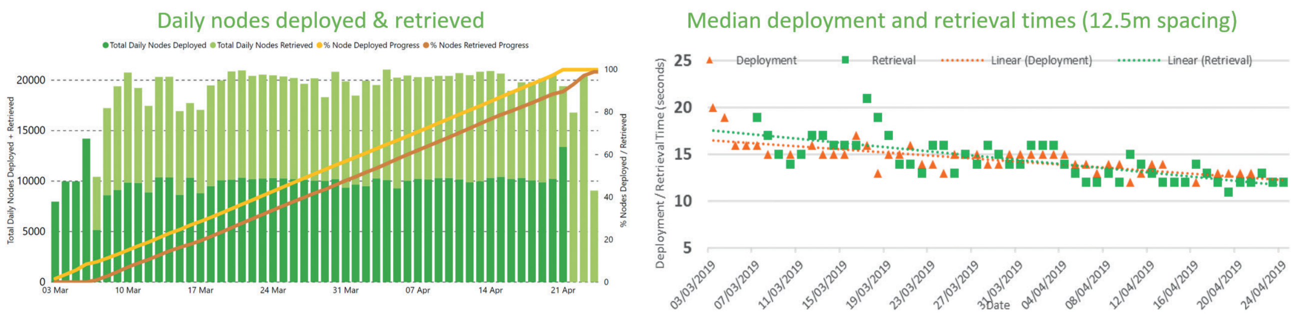

Figure 7 Operational results of the large-scale field trial with 50,800 nodes (Ourabah et al. 2020): The cews deployed and retrieved 10,000 nodes per day and achieved an average deployment and retrieval speed of 15 seconds per station (12,5m spacing).

Fast-track processing: Denser seismic data does generate much more data than conventional surveys and even if managed through adequate hardware, it is going to require a much longer period to be processed through a conventional processing sequence. The seismic industry was faced with this dilemma before (when big leaps in seismic density occurred) and fast-track processing sequences have often been used as an initial solution whilst waiting for the hardware and software to catch up (eventually allowing for more sophisticated processing to be applied). This is certainly the case again with UHD seismic data and although these 'fast tracks' will still take several months to complete for large surveys, it is still a much faster turnaround than a full production processing which could take more than a year depending on the complexity of the project. Several examples in the industry show that dense seismic provides better results at an early stage in the processing sequence (Ourabah et al, 2014) – in other words, the delay caused by the data size is balanced by the number of steps needed to reach the required quality.

Conventional Processing: As much as the fast-track approach is appealing, seismic data has always revealed more when it gets the right care and attention. For some time, decimation was the only way to handle very dense survey processing, but nowadays most processing contractors are comfortable handling a few Petabytes of seismic data as an input, delivering high quality PSDM deliverables and seismic attributes in a reasonable time-frame (Ourabah et al, 2020) (Figure 8). If we take the example of the large-scale field trial acquired by ADNOC in 2019, it was processed three times by three different stakeholders for three different purposes. It delivered different quality products, each perfectly answering the objective of their respective processing project. More importantly, this data is a great candidate for future innovative workflows and techniques that aim to reduce turnaround while increasing the quality of the subsurface image. All these approaches are not mutually exclusive and can be run in parallel or at different stages during the life of a field. The common denominator remains the dense dataset and its fitness for all these processing routes. and probably many more in the future, reducing the likelihood of requiring a new expensive seismic acquisition to improve the subsurface image and the understanding of the reservoir.

The fact that trace density impacts so many aspects of seismic processing and seismic products also reminds us of the important of considering the importance of each one of them before the survey design.

Passive seismic is another interesting by-product of continuous recording that is often overlooked. The use of interferometry to create virtual shots has resurfaced recently and this type of data is targeting the very low frequencies of the spectrum. The STRYDE node response down to 0.5Hz makes it a great receiver to capture this energy. Interferometry is used to create virtual shot gathers which are inverted to produce a long wavelet component of the subsurface velocity, a very useful product to build an initial model in the active seismic processing, especially full waveform inversion (Curtis et al, 2006).

Early adoption by the geothermal industry

While there were fewer surveys for oil and gas projects performed in 2020 due to weak oil prices, STRYDE has seen significant take-up of its nodes for seismic acquisition by the growing geothermal industry. Geothermal energy is expected to play an important role in any zero-carbon emission era, in order to provide communities with a sustainable source of energy and heat.

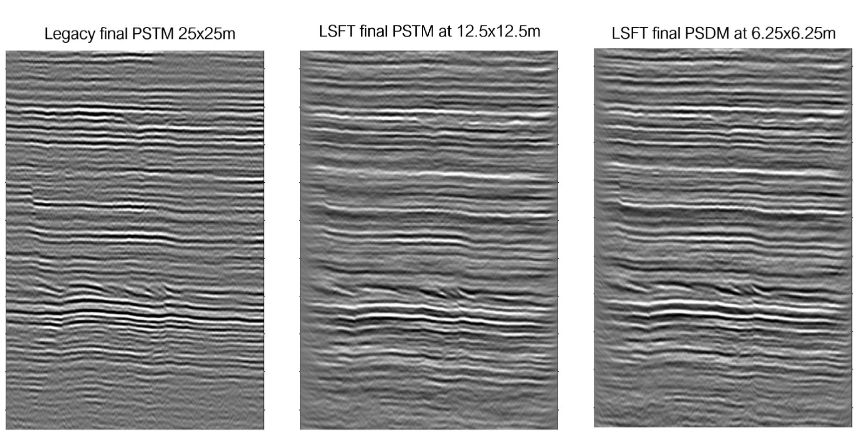

Figure 8 Large-scale field trial processing results compared to legacy data.

In order to reduce subsurface risk and quantify the energy yield from a given site, geothermal energy developers have borrowed and adapted exploration techniques and technologies from the oil and gas industry. Seismic acquisition occupies the same critical role in geothermal exploration as it does in O&G exploration. Seismic surveying also provides the necessary elements for better microseismic monitoring and alerting systems, providing the structural framework and velocity model necessary for accurate localization of the sources.

A particular constraint of geothermal exploration is that the subsurface energy source has to be near the end user. As such, associated seismic surveys are likely to be in urban or suburban areas which, although having some logistical advantages compared to remote locations, does come with additional challenges such as complex permitting, rigid or limited time windows for shooting to avoid impacting local populations, and even expensive compensation schemes for any impacted stakeholders.

Cable systems are highly impractical in this context. While in more rural environments, the landscape can be cleared to make way for cables, this is virtually impossible in urban areas without significant planning and permitting. Bulky to transport, cable systems are highly visible and attract unwanted attention, while crossing roads, tramway lines, canals require extra effort and hazards. Damage to these cables stops the whole survey as data is not recorded when communication is broken.

A move to nodal systems for geothermal exploration was necessary to keep projects financially viable and has been gradually underway in the last decade or so. Early nodes were not particularly small nor light, and some even kept the inconvenience of cables, especially when arrays were used. Nodes have kept getting smaller, lighter and very reliable, and now, seismic data is recorded by each node independently, with no need for system troubleshooting and no system down-time due to 'cuts'. The increase in productivity, besides the reduction of the operation duration and the increased density over the same period, also reduces the unit cost of the acquired data.

Small nodes also present several advantages in terms of safety and impact on the environment, for example by eliminating the need of line clearing for receivers (Brooks et al, 2018). These systems significantly reduce operational time and risk exposure: the very small footprint when deployed allows operating in dense areas without disruption and disturbance.

For example, even when terrains are not particularly rugged, vehicle-related accidents are often the highest risk in seismic operations, especially in urban environments. By reducing the number of vehicles required for transportation, scaling down the size and weight of nodes has a significant impact on safety. Additionally, the ability to easily conceal smaller nodes in urban environments also reduces the risk of theft or damage from the public.

The reduction of the crew size and the personnel interaction has enabled operators to comply with Covid-19 restrictions in place throughout Europe.

In 2020, several geothermal acquisitions were acquired in Europe using the STRYDE nimble system. The surveys were acquired in Switzerland, Belgium and France by Gallego Technical Geophysics and Real Time Seismic for multiple clients developing geothermal projects. Early 2D lines benchmarked the STRYDE system against existing nodal systems. The existing systems have subsequently been replaced with 'STRYDE only' surveys after benchmarking showed very similar seismic data from both systems, whilst STRYDE delivered significant operational efficiency benefits owing to its weight, price and volume.

A system for bespoke applications

The compact STRYDE Nimble system and its simplicity has inspired many users to test it for bespoke survey designs or applications (Figure 10). For example, STRYDE nodes have been used to trial 1-component to 3-component conversion, tightly packed spacing for 2D and 3D surveys, and coupling tests.

STRYDE nodes were also used to acquire seismic around the Scrovegni Chapel, a unique archaeological site built on the ruins of an ancient Roman amphitheatre and therefore requiring a bare minimum of seismic activity. STRYDE was the ideal solution to acquire 'near zero' footprint seismic data around the ancient structures.

The nodes can also be airfreighted, which means they can be shipped across the world for a quick test without the need to use the charging and harvesting system. STRYDE has used this 'seismic by mail' model several times with very successful

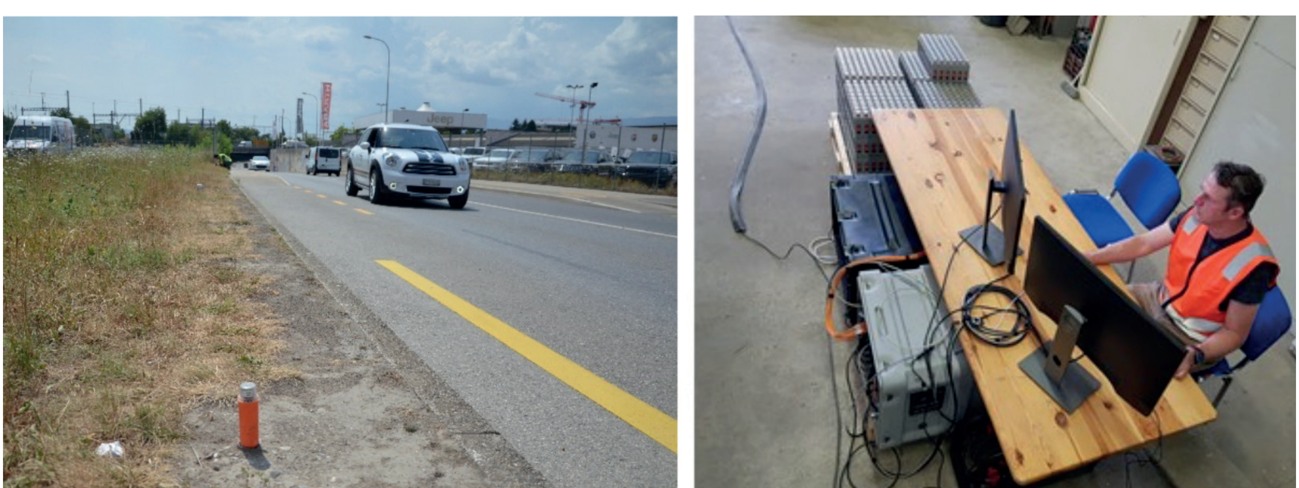

Figure 9 Left: deployment of STRYDE nodes for a geothermal survey in an urban environment. Right: the STRYDE Nimble charging and harvesting system.

Figure 10 examples of bespoke applications of the STRYDE nodal system including: 3C, super close spacing in both 2D and 3D surveys, coupling tests, and the use of Nodes for archaeology at sensitive cultural heritage locations.

results. Datasets are downloaded from the nodes when they are returned to STRYDE. Data is then sent to the client.

Conclusion

The STRYDE nodes have made UHD land seismic acquisition practical, greener, safer and financially viable. Furthermore, we are now at the stage where the benefits of UHD datasets with densities above 100 million traces per km^2 are becoming clear, setting a new target for continued development.

We have not yet reached the limit of what seismic acquisition technologies can achieve in terms of trace density, cost saving and speed. However, we are probably not far from being able to commonly acquire what we could consider 'future proof seismic data' right at the exploration stage.

UHD Seismic is part of the 'Big Data' revolution in the seismic industry, and although we still need to follow the same big steps in seismic processing, there is undeniably a potential ready to be unleashed through modern methods of data analytics. AI and machine learning are proven technologies that could not only automate major steps in processing but potentially bridge the raw data directly with the attributes sought by the reservoir team (Zhang et al, 2019). In the meantime, improvements to hardware, I/O and software will continue to make the handling of this data more manageable. Cloud computing, although not yet ready to replace conventional processing centres for this class of data, will eventually catch up as demand grows for storing and transferring the enormous amounts of data generated by UHD seismic. All of these approaches to data could further democratize access to on-demand high processing power which at present is only accessible to particularly large organisations.

Looking forward, industries may see a change in the life cycle of the seismic data, where a continuous environment of interrogation and refining could replace the traditional bursts of intensive activity interleaved with periods of quiescence. As outlined above, passive measurement of seismic acquisition is more accurate – and its insights more useful for continuing monitoring of geothermal or oil and gas projects – as the number of nodes is scaled up.

At STRYDE, we have found that once the cost barrier to UHD seismic is broken down at the receiver side, our partners across all industries can start to innovate even further when it comes to what seismic imaging can do

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