Robotization in Seismic Acquisition

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SUMMARY

The amount of sources and detectors in the seismic method follows "Moore's Law of seismic data acquisition", i.e., it increases approximately by a factor of 10 every 10 years. Therefore automation is unavoidable, leading to robotization of seismic data acquisition. Recently, we introduced a new source concept that replaces today's complex, local, broad-band source arrays by distributed source arrays of simple, narrow-band sources (DSAs). This concept is not only most favorable for blended acquisition, it is also very suitable to decentralize the entire seismic acquisition system. E.g., think of a relatively large number of autonomous shooting boats (N), each boat equipped with a simple, narrow-band source and a local vector cable with M sensors. Together, all narrow-band sources illuminate the subsurface with an incoherent wave-field that is characterized by a high spatial and temporal band-width. Since each of the N sources fires into the M sensors of each of the N cables, the number of acquired multi-offset, multi-azimuth traces equals MN^2! On land, data collection could be automated by introducing wireless geophones to be planted by robots. However, a far more interesting option is to use advanced airborne sensing technology, for simultaneously recording the seismic response of an entire area, supplemented with a sparse distribution of high-quality seismic sensors for calibration purposes. In our view such calibration sensors are 'unmanned flying objects'. In the Delphi Consortium, recently an innovation project on the robotization of seismic acquisition has started.

INTRODUCTION

The trend in seismic data acquisition is to collect more and more data with the objective to further improve the output of imaging and inversion. The number of recording channels follows "Moore's law" of seismic data acquisition, as is shown in Figure 1. From this figure it is clear that systems of more than 1.000.000 channels can be expected in the near future. Note that on land the number of geophones per channel can be in the order of fifty, meaning that fifty million (!) geophones must be planted to record the response of a single shot!

The deployment of seismic equipment on the ocean bottom is even more cumbersome. Each station has to be planted individually on the sea floor and retrieved by an underwater ROV (remotely operated vehicle).

Apart from the increase at the sensor side, we anticipate a strong increase at the source side as well. The current trend is blending (also referred to as simultaneous shooting, Beasley, 1998). Blended acquisition means that it is no longer needed to wait with firing the next 'shot' until all echoes of the previous shot have been completely captured. As a consequence the number of shots increases considerably within a given survey time, leading to improved illumination of the subsurface and better quality of the images. As will be discussed later, we introduced a new source concept for blended acquisition that replaces today's complex, local, broad-band source arrays by distributed source arrays of simple narrow-band sources (Berkhout, 2012). They are referred to as Dispersed Source Arrays (DSAs).

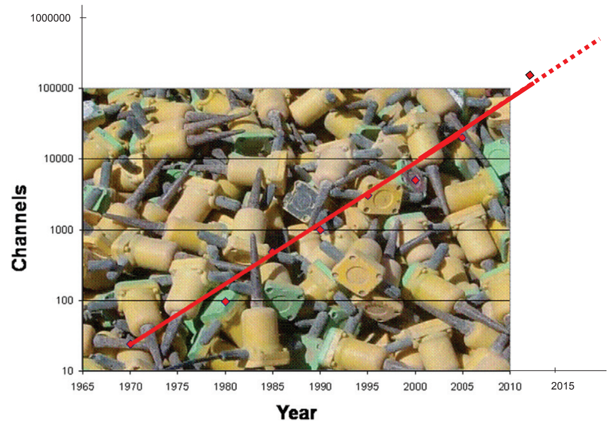

Figure 1: *The number of seismic recording channels obeys Moore's Law (based on a figure by D. Monk, Apache Oil).*

From the above acquisition trends it is clear that with the current approach, whether on land or in marine, whether at the source side or at the detector side, seismic surveying will become a logistical nightmare. Car manufacturing and production of electronic equipment are just two well-known examples of industries where logistic complexity and labor cost grew so much that an alternative had to be developed: the use of robots. This was done with great success! The robotization of seismic data acquisition seems an inevitable next step. In seismic acquisition there is even an extra argument for robotization. Seismic surveys are increasingly carried out in human unfriendly areas like polar regions, mountainous terrains and deserts. The HSE (health, safety and environment) issues associated with such extreme areas can be successfully addressed by the use of robots taking over human tasks.

Note that various projects have already been initiated by the oil industry and service providers to robotize ocean bottom acquisition. The SpiceRack™ autonomous ocean bottom node was introduced by CGGVeritas in cooperation with Saudi Aramco at the 2012 SEG meeting in Las Vegas. Earlier, Shell announced a similar project. They claim that their robots, called Flying Nodes, also operate under ice for Arctic seismic exploration. A trial using many robots is planned for 2013. Therefore, the focus in the Delphi robot project is not on autonomous ocean bottom nodes. We leave this to the industry. Our project explores unconventional solutions, emphasizing the opportunity to combine automation with new acquisition methods.

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MARINE ACQUISITION

In the concept of blending, where recording is largely continuous and shots are fired while the echo's of previous shots are still being captured, the sources may be simple. Rather than trying to produce the optimum signal by each localized single shot, leading to complex sources, in blending a diversity of distributed simple sources together produce the optimum signal, not simultaneously but in a blended fashion: *from local broadband complexity to distributed multiband simplicity*. E.g., the bandwidth of each of these simple sources may be relatively small as long as the total bandwidth is represented by the combination of the sources (compare with modern home or car audio systems, where a diversity of loudspeakers with different limited bandwidths together deliver the full temporal and spatial bandwidth of the high-quality sound). This means that the individual sources become simpler, cheaper and more robust. As already mentioned, we call this concept: blended acquisition with DSAs (Dispersed Source Arrays). Note that the sampling requirements imply that the low-frequency sources are allowed to have a much larger distance between them than the high-frequency sources. For more information see Berkhout and Blacquiere (2012).

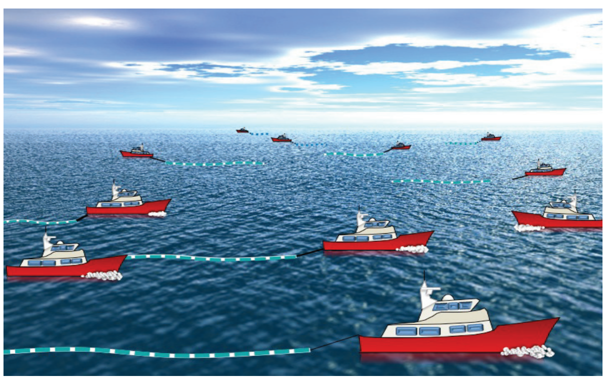

Figure 2: *A number of unmanned shooting boats, each carrying a simple narrow-band source, together forming a Dispersed Source Array (DSA) and towing a small vector cable. DSAs cover the full spatial and temporal bandwidth to illuminate the subsurface in an optimum way. Spatial sampling and deployment depth are source dependent.*

In summary: we envision an increase in the number of sources to be deployed in a blended seismic survey, each source being much simpler and cheaper than the complex and expensive source configurations that are currently used. The DSA concept is very suitable for the robotization of the entire marine seismic shooting system. An example is shown in Figure 2 where small, unmanned shooting boats carry out a seismic survey. Such boats belong to the category of USVs (unmanned surface vehicles). Each USV carries a simple source, like a single air gun, in the low or mid or high-frequency range. Note that simple, narrow-band marine vibrators would be very suitable for the DSA concept! In this way the required high spatial and temporal signal bandwidth is produced to illuminate the subsurface in an optimum way. Note that each boat also carries a local vector cable. Since each source fires into each sensor of each streamer, the number of acquired traces soon becomes huge! E.g., if there are 10 boats, each with a simple cable system of 1000 vector sensors, the number of traces acquired per blended shot record (of 10 sources) is already 10x10x1000 = 100.000. In the case of 100 such robot units, the number of traces per blended shot record (of 100 sources) becomes 10 million! We call this concept 'networked acquisition'. As will be discussed later, the DSA concept can be easily translated to the land situation by replacing the unmanned source vessels ('sailing robots') by unmanned vibroseis trucks ('driving robots'), each of which covers only a small part of the total bandwidth, but together representing DSAs that produce a spatial and temporal bandwidth beyond today's capabilities.

LAND ACQUISITION

The seismic vibrator is very common in land acquisition. It transmits a frequency sweep (or chirp) where the frequencies typically range from 5 Hz to 100 Hz. It is an enormous technical challenge to design and manufacture a single vibrating source that is capable of transmitting such a wide band of seismic frequencies without distortion. These vibrators are heavy, expensive pieces of equipment. Until today, vibrators are human-operated but one can imagine that they could be turned into autonomous vehicles. The concept of blended acquisition with Dispersed Source Arrays (DSAs) is most suitable for vibrators. Instead of using one broadband vibrator unit, a blended array of different vibrators is used with relatively narrow bandwidths (e.g., low, mid and high frequencies), together producing a large temporal and spatial bandwidth. Blended land acquisition with DSAs may create a new generation of vibrators that are optimized for a small frequency band, allowing simpler designs and smaller units for the high frequencies. Note that such vibrators could be based on other principles than hydraulics, e.g., they could be driven in an electromagnetic way.

In addition, similar to marine acquisition, the concept allows for frequency-dependent spatial sampling. DSAs are very suitable for robotization. Therefore, similar to the marine case, we aim at a feasibility study of a variety of frequency-scaled vibrator units (source robots) that together carry out the task of producing the seismic energy required for a high-quality image of the subsurface, i.e., in combination they produce a broad temporal and spatial bandwidth in an economically attractive way.

Looking at the detector side, the current manual planting of many thousands of geophones is already a major logistical operation, particularly in remote areas. This is even more true for future surveys where an order of magnitude more sensors will be deployed. To replace all (or part of) this work by robots could be an attractive option. However, the 'ultimate dream' of land seismic recording is remote sensing, see Figure 3. It means that a single device is capable of sensing a large area and replaces many thousands of individual, local sensors.

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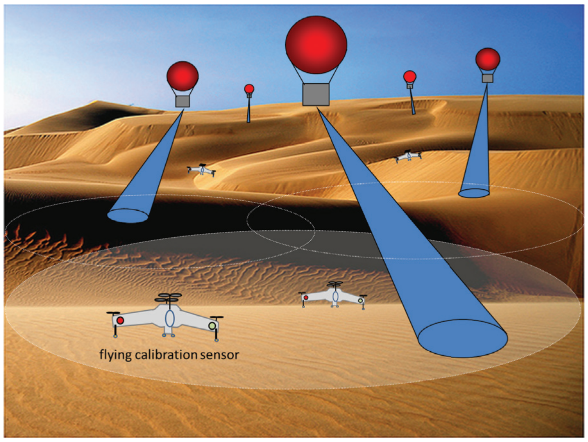

Figure 3: *Seismic remote sensing, combined with a limited number of flying calibration sensors.*

SEISMIC REMOTE SENSING IN COMBINATION WITH FLYING CALIBRATION SENSORS

Currently, the height of the Earth's surface can be determined in a very accurate way from radar interferometry data obtained by satellites. This technology has become known to a larger public after the devastating tsunami in the Indian Ocean, December 2004, see Figure 4 (Image: NOAA).

This technology is now being used in the Oil & Gas industry as well. It is feasible to measure with satellites the effects of steam or CO2 injection in reservoirs, or the effects of gas storage. In all such cases the height of the surface changes as a consequence of changes in the subsurface. Obviously, in these applications changes are slow or, in other words, changes along the surface are characterized by very large spatial and temporal scales. This explains the success.

Note that a time scale in the order of a week corresponds to a frequency in the order of 10^{-6} Hz. Of course, in the seismic method, we are interested in frequencies up to the order of 10^2 Hz. Furthermore, we are aiming at displacements of mm's down to nm's. This means that there are still large gaps, both temporal and spatial, between what current remote sensing technology delivers and what the seismic method requires. In our robot project our goal is to close this gap, starting with the very low seismic frequencies and large displacements. Note that the DSA concept is very suited for this purpose.

As mentioned before, in a DSA the individual sources are autonomous and they generate energy in a narrow frequency band only (narrowband source robots), together filling the full seismic frequency range. Such narrowband sources could also be used to produce only a single frequency. Since the Earth is considered to be a linear system for seismic frequencies, this means that the seismic response also consists of the same single frequency being, therefore, fully known. This means that a remote sensing detector system needs to determine at each surface location two parameters only: amplitude and phase of that particular frequency component. The spatial sampling intervals could be chosen according to the Nyquist-Shannon criterion for the frequency under investigation, i.e., very large for the very low frequencies. The duration of such an illumination & detection cycle could be chosen sufficiently long, such that a desired signal to noise ratio is reached. In the next acquisition cycle a different frequency component is chosen. In Figure 6 shows a snapshot of the response of a monochromatic source of 5 Hz at the surface.

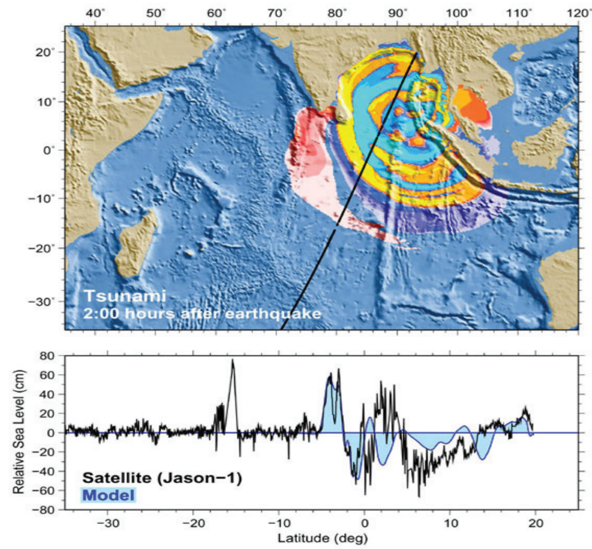

Figure 4: *Tsunami wave height as measured by satellites two hours after the earthquake (image: NOAA).*

We will follow a step-by-step approach (moving up in scale):

- Investigation of today's and tomorrow's remote sensing capabilities for measuring the very slow changes of the Earth's surface ($f<10^{-6}$) on a mm scale;
- Outline of the steps required to measure with remote sensing faster changes of the Earth surface than the current super-low frequencies ($f>10^{-6}$) and at smaller spatial scales;
- Design of an acquisition system that combines illumination with DSA robots and detection with SRS.

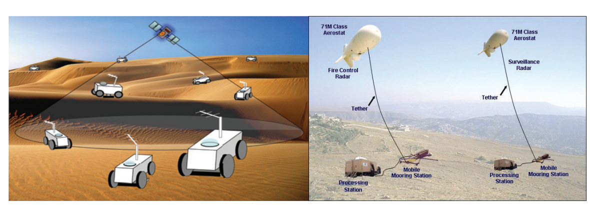

Figure 5: *Left: Combining illumination with the Dispersed Source Array (DSA) concept and detection by the Seismic Remote Sensing (SRS) concept. Right: Alternatives to satellites, like Aerostats (defenseindustrydaily.com) have properties that are better suited to the seismic application.*

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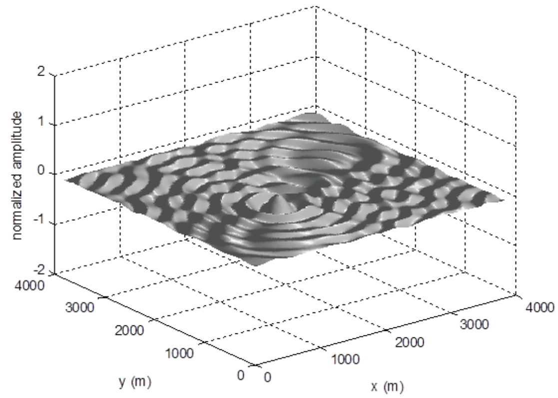

Figure 6: *Monochromatic (5 Hz) 3D seismic shot record: amplitude at the surface (one snapshot); notice that the area is 4 km x 4 km.*

To calibrate the Seismic Remote Sensing information, it is supplemented with sparsely distributed calibration sensors 'unmanned flying objects', for example the ATMOV (autonomous transition multi-rotor observation vehicle). ATMOV is the latest technical creation from the Micro Aerial Vehicle lab, located at the faculty of Aerospace Engineering at Delft University, see Figure 7. Motivated researchers, together with a team of PhD and MSc students work on swarms of aircrafts that fly autonomously, recognize and avoid obstacles.

Important characteristics of ATMOV are its ability to take-off and land vertically and to hover like a helicopter, as well as its ability to fly efficiently like a plane. Its design is basically a wing, which is vertically oriented when taking-off or landing. In the take-off and landing phase all four rotors are used. Once in the air, the vehicle will rotate 90^{o} and orient itself horizontally for efficiently flying larger distances, using only two of its propellers (see Figure 8).

In our vision a swarm of ATMOVs provides its support in the remote sensing scenario as 'flying calibration sensors': the ATMOVs carry the calibration sensors to the required positions, perform the seismic measurements and return to their base once the 'mission' has been completed.

Figure 7: *ATMOV is the latest technical creation from the MAV-lab, the micro aerial vehicle lab, which is located at the faculty of Aerospace Engineering at Delft University.*

Figure 8: *A hovering ATMOV to plant a calibration sensor. When flying larger distances, the wing is rotated 90°.*

In the Delphi robot project a small swarm of 'unmanned flying seismic sensors' will be developed that together fly to the acquisition area, occupy their respective positions, record seismic waves, fly back to the original position and deliver seismic data.

CONCLUDING REMARKS

Without automation, the trend of increasing numbers of sources and detectors in seismic acquisition will level off.

The DSA (distributed source array) concept is very suitable to robotize the seismic shooting system. In the case of marine acquisition think of N autonomous shooting vessels, each boat equipped with a simple, narrow-band source and a single streamer with M vector sensors. Such a system already results in MN^2 wide-azimuth traces per blended experiment. In the case of land acquisition think of a plurality of autonomous, simple, narrow-band vibrators.

For sensing on land, the 'wholy grail' is to combine advanced airborne sensing technology, for simultaneously recording the seismic response of an entire area, with a sparse distribution of high-quality sensors for calibration purposes.

In the Delphi Consortium, a long-term innovation project on the robotization of seismic acquisition has started.

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EDITED REFERENCES

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REFERENCES

Berkhout, A. J., and G. Blacquière, 2012, Utilizing dispersed source arrays in blended acquisition: 82nd Annual International Meeting, SEG, Expanded Abstracts, **2012**, http://dx.doi.org/10.1190/segam2012-0302.1.

Berkhout, A. J., 2012, Blended acquisition with dispersed source arrays: Geophysics, **77**, no. 4, A19–A23, http://dx.doi.org/10.1190/geo2011-0480.1.