Investigation into the use of Autonomous Vehicles for Subsea Seismic Acquisition

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Abstract

Seismic acquisition is an integral part of the hydrocarbon production cycle and is used extensively during exploration to concurrently identify and characterize the size and location of oil and gas reservoirs. This paper investigates the feasibility of utilizing autonomous vehicles in hydrocarbon exploration to reduce imaging costs and improve image quality. The paper includes a brief literature review on current technology and based on this presents and implements in MATLAB a methodology for designing an AUV(s) capable of replacing ROVs, typically used in node placement/collection for ocean bottom node (OBN) surveys. The AUVs designed by the methodology are shown to be comparable to those available 'off the shelf' from Kongsberg Marine, indicating that contemporary AUV technology is apposite for use in OBN surveys.

1. Introduction

Decreasing oil and gas (O&G) prices and increasing productivity of unconventional O&G production (for example, shale gas) has made cutting costs and improving productivity a matter of not just profits but continued survival for many O&G firms. (Deloitte, 2016) Moreover the continued push towards O&G exploration and production in deepwater, ultra-deepwater and other challenging environments (subsalt reserves, rugged topography and complex overburdens) is creating an environment where small improvements in geophysical surveying, used primarily in the exploration stage of O&G production, is of disproportionate value to many firms.

This project aims to establish the feasibility of using commercially available autonomous vehicles for subsea seismic data acquisition, in addition to proposing a suitable means by which to achieve this, the ultimate goal being to develop a strategy capable of delivering significant cost reductions. By developing a concept design methodology, which determines the required dimensions, battery capacity and endurance of an autonomous underwater vehicle (AUV) suitable for replacing the remotely operated underwater vehicles (ROVs) used in ocean bottom node (OBN) surveys, the paper demonstrates that existing AUV technology, available from suppliers such as Kongsberg Marine, is sufficiently mature for automating node placement, collection & roll along in OBN seismic surveys.

2. Process

2.1 Feasibility Investigation

To examine the feasibility of AUVs for seismic acquisition, three main steps were undertaken; a literature review on seismic acquisition technologies, identification of ‘bottlenecks’ in current methods and the concept design of an AUV suitable to overcome the identified bottlenecks.

Should the conceptual AUV be achievable using existing commercially available technology (identified by simply comparing against off the shelf AUV specifications) this would indicate/support the contention that AUV technology is sufficiently mature for use in seismic acquisition.

2.2 AUV Design Process

Given the extensive variety of factors and variables that must be taken into account and the highly iterative nature of design, a separate methodology and MATLAB code was developed to aid the design process. This process is illustrated in Figure 1.

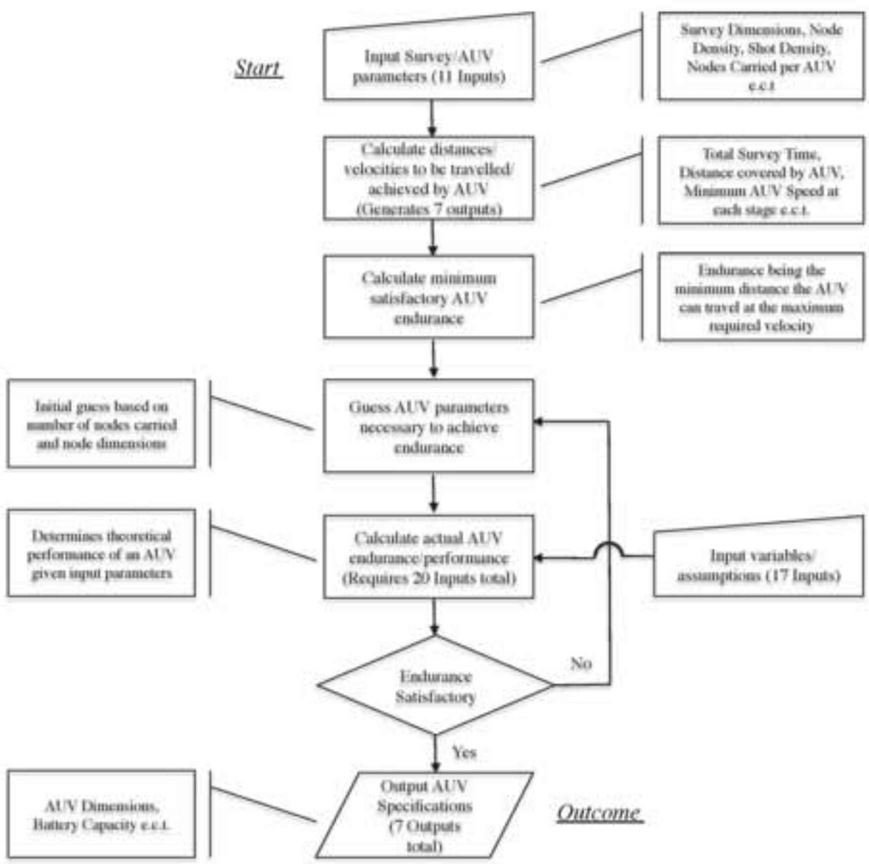

Figure 1 Process implemented in MATLAB to calculate AUV specifications necessary to achieve given design; requiring 31 inputs total. Note - the flowchart is specific to OBN surveys

3. Results and Discussion

3.1 Literature Review & Bottlenecks

At present there exist three distinct methods of seismic acquisition: towed streamer (TSA); ocean bottom seismic/cable; and OBN. Other approaches are possible, such as vertical seismic profiles, which are typically not utilized for initial exploration. (Mondol, 2010, Alfaro et al., 2007) Each method, whilst remaining unique from the others, can be modified considerably in order to best meet the desired survey outcomes.

TSA is a highly capable and frequently utilized technique typically sufficient for initial O&G exploration. Whilst effective, TSA is prone to issues with inadequate image illumination, ghosting, streamer feathering, noise, obstructions and tangling, all of which are difficult to overcome and have a deleterious effect on image quality. (Mondol, 2010) Alternative configurations of TSA, such as wide-azimuth geometries, are capable of overcoming some of these issues, particularly those associated with insufficient illumination, yet no configuration offers a panacea to all these problems. (Ronen et al., 2009) Additionally TSA approaches are unable to capture shear wave data (as shear waves do not travel through liquids), and struggle in capturing low frequency information, both of which have been proven to provide enhanced resolution and otherwise improved image quality. (Hardage, 2014)

The main competitor to the TSA is the use of ocean bottom seismometers; OBNs being used most frequently. OBNs are a more recent development in subsea seismic acquisition, with the first large-scale implementation occurring in 2005 to image the Atlantis oilfield in the Gulf of Mexico. (Mitchell & Grisham, 2006) This first implementation was considered highly successful, and since then OBN's have become increasingly popular due in large part to the very high quality images produced, and capability for 4D imaging. OBN's have a number of advantages over TSA, given they are capable of full waveform recording (shear and pressure waves), mirror imaging, 4D imaging in addition to capturing long offset, full azimuth data and low frequency energy. (Olofsson, 2011) They are also unimpeded by obstructions unlike TSA.

OBNs are not free from drawbacks, the main one being cost. From discussions with Woodside the rule of thumb is for a given survey OBNs cost between 5-10 times as much depending on factors such as water depth, location etc., but produce far superior imaging in comparison to TSA. The two main 'bottlenecks', contributing to the high relative costs, are the placement of nodes by ROVs and the necessity to utilize a dense shot carpet when imaging (Ronen et al., 2009). Both issues, in addition to being labor intensive, increase the time taken to survey a given area which otherwise could be 'passed over' once at ~4 knots if using conventional TSA.

3.2 Identification of the Technique Best Suited to Autonomous Vehicles

Given the fundamental limitations inherent to the towed streamer approach, and the development of full waveform inversion, which is ideally suited to ocean bottom seismic acquisition, it appears that OBN's may offer the best candidate for adaptation/implementation with autonomous vehicles. Moreover given one of the key 'bottlenecks' associated with OBN's is ocean bottom placement, specifically the costs and time associated with using ROVs to do so, any autonomous vehicle which could perform the same function as an ROV, potentially with greater speed and accuracy, could significantly reduce the costs associated with OBN surveys.

Considering also that 3D TSA imaging has been utilised since the 80's and is hence relatively mature technology without major bottlenecks/issues, this paper focuses on the use of AUVs to replace the need for ROV OBN placement.

Autonomous Robotics Ltd have been developing, for the past 15 years, combined nodes/AUVs capable of self positioning/propulsion removing the need for node placement entirely. This approach introduces a great deal of redundancy in the form of AUVs (being the nodes) simply idling on the ocean floor during the shooting phase, until they receive a signal to change position/return to the boat, an approach which has yet to deliver a useful prototype. Given the costs associated with equipping each node with sophisticated engines, sensing and communication equipment among other design concerns this paper will not consider this approach but rather look at automating the ROV aspect of OBN surveys.

3.3 OBN Roll Along Acquisition and AUVs

OBN acquisition typically involves a roll along process, whereby as a shooting boat (firing an airgun at specified frequncies) traverses a shot carpet/shooting area, ROVs place nodes in a grid pattern on the ocean floor. Once all nodes are placed and the shooting boat 'zipper' has moved along sufficiently, 'redundant nodes', meaning those nodes that are no longer recording useful seismic traces, are 'rolled along' until the end of the survey area is reached at which point they are collected. A graphical illustration of this process is given in Figure 2.

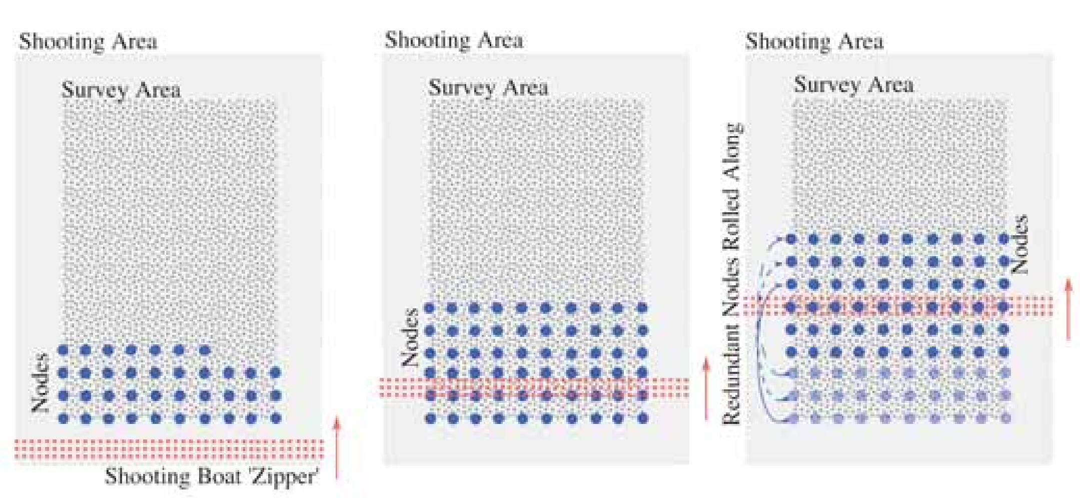

Figure 2 Graphical illustration of OBN roll along acquisition technique

As we desire to automate the ROV node placement process, an AUV carrying n-nodes must follow a pre-specified path to place, roll along and collect OBNs during a seismic survey. The distance and speed the AUV must travel is therefore a function of the survey parameters (node density, survey area & depth e.c.t.), the number of nodes that may be carried by an AUV at any one time and the number of AUVs in service.

MATLAB code, based on the methodology in Figure 1, was created to calculate the distances and velocities an AUV(s) must travel to perform the same function performed by ROVs, with the velocity being that required to keep up with the shooting boat 'zipper' (see Figure 2).

Based on these calculations the code then ‘designs’ an AUV capable of achieving the desired distances/velocities (assuming that for each AUV in operation a separate AUV is being recharged on the support vessel).

Results from the MATLAB code (Table 1), where the survey depth was assumed to be 700 m, survey area parameters were approximated from the theoretical OBN survey given in Olofsson, 2011, and OBN node parameters are taken to be equivalent to the Fairfield Z700 Model Node.

		Units	AUV 1	AUV 2	AUV 3	AUV 4	AUV 5
Input Variables	Number of AUVs	-	1	1	1	2	2
	Nodes Carried/AUV	-	1	3	5	3	10
Corresponding AUV Specifications	AUV Mass (Dry)	kg	290	320	400	320	870
	AUV Length	m	2.4	2.5	2.7	2.5	3.4
	AUV Diameter	m	0.48	0.49	0.53	0.49	0.69
	AUV Battery Capacity	kWh	4.5	6	7.2	6	12
	AUV Endurance (at 4.5 knots)	hours	13	11	11	11	17
Survey/AUV Characteristics	Total Distance Travelled/AUV	km	9400	4300	3300	2100	1400
	Maximum Speed Required	knots	2.2	0.76	0.55	0.38	0.31
Notes	AUV velocity fixed at 4.5 knots to allow comparison between AUV configurations Total survey time 146 days (Assuming shooting boat velocity of 3 knots) Survey depth and total area 700 m & 229 km^2 respectively						

Table 1 Selected output values from MATLAB code, implimented with similar parameters to the theoretical OBN survey described in Olofsson, 2011

A comparison between AUV 1 and AUV 5 (from Table 1) to two REMUS class AUVs designed and manufactured by Kongsberg Marine is provided in Table 2. It is apparent that AUVs designed by the MATLAB code are similar to those available from Kongsberg Marine, the primary difference being a slightly poorer endurance and a lower slenderness ratio than the Kongsberg Marine products.

	Units	AUV 1	AUV 5	REUMUS 600	REMUS 6000
AUV Mass (Dry)	kg	290	870	220 - 385	862
AUV Length	m	2.4	3.4	2.7 - 5.5	3.96
AUV Diameter	m	0.48	0.69	0.32	0.71
AUV Battery Capacity	kWh	4.5	12	5.4	12
AUV Endurance	hours	13	17	< 24	~ 22
Slenderness Ratio	-	5	4.9	~ 9.5	5.6

Table 2 Comparison of MATLAB AUV designs to comparable AUVs produced by Kongsberg Marine

In terms of basic AUV performance characteristics, the technology required to automate ROV node placement for survey design is achievable with ‘off the shelf’ technology (Table 2).

4. Conclusions and Future Work

This paper presents a methodology (Figure 1) for designing an AUV capable of replacing ROVs in a full size OBN survey and provides results from the implementation of the given methodology in MATLAB. The results (Tables 1 & 2) demonstrate that AUVs are likely well suited towards implementation in this application, indeed the AUVs designed by the methodology are very similar to those available 'off the shelf' from Kongsberg Marine and other AUV manufacturers.

Further work is required to validate the suitability of AUVs for seismic acquisition. Specifically no mechanism/control process for node placement/collection has been designed or modelled and numerous assumptions need to be validated (for instance hotel load was assumed to be ~ 30 W); moreover exact hardware specifications, logistical details, survey considerations and a variety of other issues need to be ironed out before one can conclude that AUVs are suitable for this application. Additionally, future work should seek to define suitable test outcomes, outlining an appropriate testing methodology that may be implemented to validate the final AUV design, and ensure it is sufficiently scalable for future implementation.

5. Acknowledgements

The author would like to aknowledge the support and guidance provided by supervisor Charitha Pattiaratchi, in addition to that provided by client mentors Jeremy Fitzpatrick and Fabio Mancini.

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