Method for Steering a Vessel with Towed Equipment

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***Abstract*— This document presents a new method to automatically control the autopilot of a survey vessel so that the towed equipment follows some predetermined tracks even in case of sea currents.**

Keywords—seismic, navigation, vessel steering, 4D, towed equipment.

I. Introduction

In the marine seismic acquisition industry, a vessel usually tows one or more acoustic sources and several streamers. In the survey industry a vessel may be towing some sonar, sidescan sonar or other type of equipment. The method presented here has been developed for the seismic industry and is applicable to the survey industry. Its purpose is to control a vessel autopilot so that the towed equipment follows a predetermined track.

A. *Marine Seismic Acquisition*

In the marine seismic industry, there are 5 main acquisition schemes [1].

In the first one, called 2D, the vessel is towing one streamer to perform a general description of a large area by following sparse lines. It has been used for years to find oil and gas.

The second one is used for what is generally called site survey. The purpose is to get a detailed description of a small area before the installation of a platform or a well. The area is therefore covered with high-density measurements. The seismic data are used to detect underground hazards like shallow gas pockets.

The third method, 3D, is more complex as it requires a full coverage of the area and the data are then processed as a whole to produce a 3D volume of the subsurface. The seismic vessel is towing several streamers along parallel lines. Those lines are ideally spaced so as to produce a full coverage with the measurements.

The fourth method, 4D, known also as time lapse survey, is a repetition of a survey over time to study the evolution of a reservoir, like the subsidence due to the oil recovery or the increase of the reservoir volume due to the water pumped in the wells. In 4D, the repetition of a survey is a monitor survey that is compared to a baseline survey.

The last acquisition scheme comprises multi-azimuth, wide-azimuth or even full-azimuth surveys and is used to map the subsurface from different angles to better “see” under large seismic obstructions like salt domes. Seismic acquisition uses mainly reflection of an acoustic wave to map the sub-bottom. Because of the direction of the slope of the geological targets, the acquisition needs to be performed in a given direction. If the geology is complex, then surveying along several directions enhances the image.

B. *Marine Non-Seismic Survey Acquisition*

When a survey purpose is to survey a large area with towed equipment, like multi-beam echo sounders or side scan sonars to name a few, it seems more efficient if the towed equipment follows equally spaced lines or any other pre-determined pattern rather than the vessel, to avoid non-uniform coverage due to variable current.

C. *Towing Distance*

Because of the hydrodynamic forces, it is difficult to sink towed bodies or to deflect them on the side.

To tow many streamers, those have to be deflected on the side, and the head of the streamers spread may be far beyond 500 m behind the towing vessel. To acquire data with a towed fish close to the bottom in deep water, it is similarly necessary to deploy it far behind the towing vessel.

With current, the towed equipment deviates from the ship track over the ground; the angle the towed streamers makes with the ship track over the ground is commonly called the feather.

II. The Currents

A vessel may encounter many types of currents.

Close to the shore or in areas like the North Sea, the main current is often a tidal current. It is periodic and changes with the tide.

Close to the shore, when the vessel path crosses a river mouth, there is a current induced by the river flow that usually varies according to the rainfalls or other meteorological parameter.

There are also the main currents that travel through the oceans, like the Gulf Stream. Those are always travelling the same way, so it seems quite easy to manage.

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Then there are the loops and eddies. Unfortunately, a current like the Gulf Stream doesn't travel straight from the Bahamas to Norway but it bends and forms eddies. In the Gulf of Mexico, the current forms a loop which position varies with time.

Some currents are due to the wind and other phenomena and they can even be canalized by the bathymetry.

So currents are encountered all over the world, from coastal waters to the middle of the oceans. They usually vary with time, sometime periodically, sometime not. The currents are often not very strong, usually lower than a knot, but they can reach occasionally 2 knots and even more in very specific areas, like a pass cutting a coral reef. Seismic vessels travel quite slowly, usually between 4 and 5 knots. So even a weak current causes some feather to the cables towed behind.

III. 3D Navigation

A. The Racetrack Navigation Pattern

Once some interesting geological targets have been identified during the 2D survey, a smaller area is defined and acquired as 3D. Usually, in 3D, groups of paralleled lines, called swaths, are acquired in a same direction. At the end of a first line, the vessel turns with a large turn radius to pick up a second line several miles away and acquires it in the opposite direction. After the acquisition of that second line, the vessel turns along a second line change to get back to the first swath and sails along a third line adjacent to the first one. Because the survey is acquired following a succession of parallel straight lines connected by curves resembling half circles, the acquisition pattern is called a racetrack as shown in Fig. 1.

B. Steering the Seimic Vessel

1) Generalities

If there is no current and no wind, the vessel has just to be steered along the predetermined tracks sometimes called pre-plot and the towed spread follows nicely behind. But usually there is some current and the vessel has to be steered accordingly.

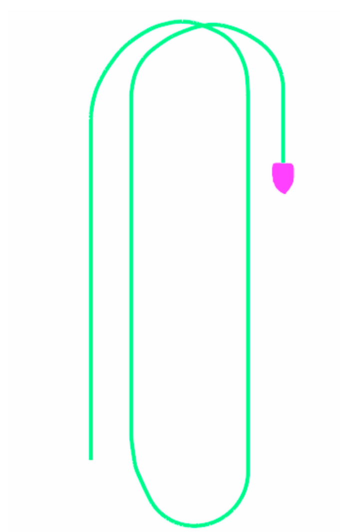

Fig. 1. Example of a racetrack acquisition pattern

There are two main ways to steer the vessel depending on the purpose.

If it is known in advance that the 3D survey will serve as a baseline for a 4D survey, some companies choose to have the pre-plots strictly followed. But the most common way to perform a 3D survey, which is the most efficient, quicker and cheaper, is to "steer for coverage".

2) Steering for Coverage

Let's look, for example, at a vessel shooting two adjacent lines separated by 250 m with a spread towed 500 m behind the vessel. With a 0.5 knot current from the side and a vessel sailing at 4 knots, the head of the spread is about 60 m on the side and is towed at an angle (the feather). If the vessel is sailing on the pre-plot then the head of the spread is already 60 m away from the pre-plot.

So instead of following the pre-plot with the vessel, the navigator instructs the vessel to follow a line parallel to the pre-plot, based on the feather. The navigator looks at a real time coverage plot. When the feather changes, either it creates a hole in the coverage between the adjacent lines or the vessel acquires data already acquired by a previous line. Fortunately some small holes are acceptable and don't require the vessel to come back, nevertheless the navigator usually instructs the vessel to move to reduce the hole or increase the coverage. In the end, because of this procedure, the covered area is not straight but wobbly and so is the vessel track over the ground.

If the holes are too wide or too long, then the vessel is required to come back and shoot what is called an infill. If the lines are sailed too close with too much overlap, then the vessel needs to sail extra lines to cover the swath, lines that are also called infills. Those infills are quite costly in time and should be avoided if possible.

C. The Steering Equipment

The vessel is not steered by the crew on the bridge, but by a navigator sitting in front of a computer screen.

The navigator uses an INS, Integrated Navigation System. The INS commonly used in 3D are Spectra and Orca from Concept Systems and SeaPro Nav from Sercel. It gets the positions from external systems, like a GNSS, Global Navigation Satellite System) and acoustic systems for the underwater equipment and it computes the positions. It also knows the pre-plot to be followed and it performs the coverage maps.

The vessel is steered by an autopilot that controls the heading like the Robtrack or the Kongsberg cJoy that are commonly used in marine seismic acquisition. The INS sends information and commands to the autopilot. The navigator tells the INS where the vessel should go, sideways, relative to the pre-plot.

So the way it works is the following:

- The navigator checks the coverage and if there is a hole or an overlap it instructs the INS to move the vessel sideway by a given cross-line distance.

- The INS knows the vessel position and heading relative to the pre-plot and using the new instruction from the navigator computes an information and command string, which it sends to the autopilot.
- The autopilot modifies the vessel heading to follow the command from the INS, using a PID (Proportional-Integral-Derivative) controller.

IV. 4D Navigation

A. Repeatability

4D is about repeating the same survey, but there are at least two ways of defining the repeatability so that the two surveys data may be compared.

The first way it about measuring the same point on the seafloor or at the geological target level.

In the second way the purpose is to perform the same measurement; the data from a same point on the seafloor or the target level are acquired with the same incident angle from a same direction, so it means they are acquired from the same source point and the same receiver point. That way, the acoustic travel through the overburden is the same and therefore it reduces the noise in the 4D difference coming from the overburden heterogeneity. The acoustic signal recorded on a receiver is a trace. One way to determine the difference between the monitor and the baseline is to compare each baseline trace with each closest monitor trace.

In the end one may determine, for example, where the reservoir is depleted because it creates a local subsidence or whether two parts of the field communicate or not and whether new wells need to be drilled. For a better comparison, it is also important to have a good knowledge of the tide so as to have a good reference to measure the subsidence. An important variation of sound velocity in the water may also hide the 4D information one is looking for.

One very common way to qualify the repeatability is to use the distance dS between the sources of the baseline and the monitor and the distance dR between the receiver of the baseline and the receiver of the monitor for a given trace as in [2] and [3].

B. The Technics to Achieve the Repeability

1) The Currents

If the currents in the area are tidal currents, the main rule is to match the currents for each monitor line with the currents from the corresponding baseline line.

When the currents are not predictable, it is not easy to match the currents, but there are different types of forecasts that may help.

2) The Receivers

There are at least two main possible strategies:

- Steer the streamers using steering streamer devices as in [4].
- Overlap the acquisition by dense streamers or by adding extra streamers on the outside of the spread as presented in [2].

3) The Source

There are two main strategies to manage the source positioning on the pre-plot:

- Steer the vessel so that the source towed behind gets on the pre-plot.
- Steer the source to the pre-plot position, by moving the source itself.

The best way to manage it is to handle the low frequency movements with the vessel steering and the high frequency movements with a source steering system.

Source steering is very popular among the seismic acquisition companies clients and is often a requirement. The automated vessel steering is never a requirement despite the fact that a good vessel steering system is very efficient. Even good navigators with good conditions can achieve a better result without source steering than a bad navigator with source steering and the same conditions.

Modeling shows that a good navigation system is more important than source steering. Despite that, most seismic contractors offer automated source steering and only one currently offers automated vessel steering, but according to the published results in [5], this vessel steering is far from as effective as could be expected from modeling.

V. Source Steering

A. Source Steering and Vessel Navigation Issue

Because source steering is used as a differentiating technology there are many patents covering many different technologies to achieve source steering. More than 40 patents have already been applied for and new applications appear regularly. Some are based on winches either on the back deck [6] or underwater [7], others on hydrodynamic deflectors [8], [9] and [10].

The main drawback of source steering is that it does confuse the navigator who manages the vessel steering. If the vessel is slowly getting off course because the current is slowly changing, the source steering device will properly compensate for it until it reaches its limit and then it is as if there is no source steering any more, back to square one or even worse. When the vessel reaches the source steering limit she may already be heading in a direction far away from the right course, so the time it will take just to correct the heading she would have travelled even more off course. Coming back requires an important change in heading and that’s how the track begins to oscillate.

If the system is only reaching its limits now and then, the source position is overall better with source steering than without, but it is yet possible to achieve a better performance.

It is very understandable, for the navigator, not to change anything when the source is on its pre-plot. How can the navigator guess what to do with the vessel when the source is already on the pre-plot? Well, the navigator can check the source steering parameters, if available, to adjust the steering accordingly, but those parameters may not be obvious to use. Imagine that you are given the wing angles of the wings attached on each side of each of the starboard and port sources, that's not so easy to use for real time steering. So, in the end, the navigator chooses not to intervene and to let the source steering device handle the deviation until it reaches one of its limits.

One main issue with source steering is to couple it properly with the vessel navigation. Some methods are more efficient than others, some are quite inefficient and some are even worse than nothing.

If the chosen steering method, either with manual steering from the navigator or automated steering, usually reaches the source steering device limits before it acts on the vessel steering, the solution is to have the most possible powerful source steering device to overcome the lack of coupling with the vessel navigation.

There exists a patented method to couple the source steering device with the vessel navigation [11]. The purpose of this method is quite simple; the vessel is steered as if there was no source steering so as to handle the low oscillatory movements of the vessel while the source steering handles the remaining small, high frequency deviations.

B. Source Steering Control with the Virtual Source Concept

Let's consider a source steering device using a winch.

An encoder is able to tell the position of the winch from which the length of cable paid in or paid out can be derived.

If the cable is situated between a lead-in and a source array [7], when the cable is paid in, the source array and the lead-in get closer to each other. If the cable is not perpendicular to those, the distance by which they get closer is smaller than the length of cable paid in. In some configuration, the lead-in passes under the source, in which case the winch will only move the lead-in upward without any cross-line steering. So the prospectors need to be aware that they cannot always use their standard rigging configuration if they need an efficient source steering. Sometimes habits die hard. Nevertheless, the lead-in depth variation is of no interest for the source steering, so it has to be taken into account.

In the water, the source array moves toward the lead-in while the lead-in moves toward the source array. After some trials, it is easy to determine how much a source array moves cross-line for a given cable length. Conversely, it is possible to compute where the source would have been if it had not been steered, which corresponds to a "neutral" length of cable.

In [11], the position the source would have had if it had not been steered is called the virtual source position.

The principle behind the virtual source method is that the vessel is to be steered the best possible known way so that the towed source is as close as possible to the pre-plot while a source steering device handles the remaining small deviations. That's the most efficient way to do it and to couple the two systems, vessel steering and towed equipment steering.

Of course, if the vessel steering is manual, it is a lot of work for the navigators. The navigators are also prone to errors and it requires a constant focus, which is not always possible as he/she has other tasks to perform.

From what can be gathered from booth presentations and discussions, some prefer keeping the vessel on its track without any intervention for a long time, while all the work is handled by the source steering device, which needs to be consequently bigger and faster, and others rely only on the navigator steering manually the vessel.

Those two methods are performing quite well, in many cases, when the current is not changing too much. Those seem to be the two methods currently in use in the marine seismic acquisition industry.

The virtual source method is quite difficult for the navigator to handle when he/she is manually steering the vessel if he/she doesn't have the proper display. The navigator has to trust a virtual source, and he often doesn't understand why he has to maneuver the vessel when the source steering device can handle the deviation. It is recommended not to display the real position of the source on the INS control screen with the virtual source method. If the actual position of the source is not displayed on the screen, the navigator can steer easily the vessel as he has always done before the source steering device has been installed. It is unfortunately counter-intuitive that it is better not to see something to better control it, so in the end the actual source position is displayed on the navigator screen.

Unfortunately, watching the real source position on the screen does confuse the navigator ability to steer the vessel. Let's imagine that the source is off to starboard, the navigator instructs the vessel to go to port, but even before the vessel change of track can affect the source towed 500 m behind, the source is back on its position thanks to the source steering device. So the navigator action is to cancel its previous instruction. The source is towed something like 500 m behind, so it takes some time, at least a couple of minutes before the vessel movement sideway changes the source position cross-line.

It takes time to train the navigators to properly steer the vessel, with a source steering device, that's why what is gained by implementing a source steering device is easily lost in the vessel steering, either manual or automatic, if not properly designed.

VI. Undershoot and Multi-Vessels Operations

In oil fields, there are many man made obstructions such as drilling rigs, production facilities and platforms. There are also some natural obstructions.

In that case, a dual vessel operations called undershoot is performed. One vessel tows the acoustic source and the other the streamers. The measurements, the reflection points, lie in between the source and the receivers so either close to the obstruction or under it, hence the name.

Undershoot are also performed in 4D. As 4D is about surveying an oil field in production, there are usually many obstructions and several undershoots to perform.

In the case of an undershoot source vessel, the towed source lies closer to the vessel, probably less than 100 m, so it would take a fifth of the time for the vessel movement sideways to induce a source cross-line movement compared to a vessel towing streamers and a source at 500 m. In that case the vessel steering may be enough and the main issue may be the stability of the source in case of waves. Now, with the current downturn in the seismic industry, many large seismic vessels are used as source vessels, but usually it is smaller, dedicated rented source vessels without source steering which are used for the undershoots. In that last case, installing a vessel steering in the INS may be easier if the vessel is already equipped with an automatic pilot, which is not always the case, than installing a source steering system.

VII. Seabed Operations

There are other types of seismic operations like the seabed operations. The two main types of equipment are the nodes, which are individual recorders that are laid on the floor and may or may not be linked to each other by a cable, and the cables like streamers, usually laid on or buried in the seafloor. In some case, the cable can be left for several years so as to allow regular 4D acquisition to monitor the field [12].

In the Ekofisk life of field seismic [12], the receivers are trenched cables and the acoustic source is installed on one of the Ekofisk supply vessels.

As mentioned earlier, a good repeatability is required for 4D both for the receivers positions and the source positions. In the Ekofisk configuration, the receivers are always at the same place. As for the source, the best would be to have a supply vessel with an automatic pilot, in which case a vessel steering system would be very easy to install, once integrated in the source vessel INS.

VIII. Towed Equipement

While the spread towed by a seismic vessel is quite impressive, other types of equipment than seismic sources and streamers may be towed.

In [13], a fish is towed under a seismic source to measure its far field signature. There are two points in this example worth mentioning:

- The towed fish is underwater and doesn't usually send its position to the vessel.
- If the current is the same at the fish depth as it is at the source depth, the fish should be below the source if the correct length of cable is deployed, unless one of them is deflected or steered.

A. Positionning the Towed Fish

In [13], the towed fish was deployed so as to be under an acoustic source towed by the seismic vessel. The purpose was to measure the far field signature just under the source: the target.

The source was deployed behind the vessel without being deflected. Very often, a seismic vessel tows two acoustic sources that are deflected on each side, so as to be towed 50 m apart for example.

The towed fish was also deployed behind the vessel, without being deflected. The towed fish position was determined by an USBL (Ultra Short Baseline) attached under a surface buoy also towed. The measured positions confirmed the towed fish was staying close to the target.

In an other instance, because the vessel was so equipped, the USBL was installed on a pole extending below the hull [13]. In that instance also, the towed fish was staying close to the target.

As long as the current is the same at the surface and at the towed fish depth, the towed fish position can be derived directly from a surface towed body, as long as this surface towed body is towed from the same point and as long as it is deep enough so as not to be deflected by the wind. The distance from the vessel can be derived from the depth of the tow fish and the length of cable paid out.

B. Methods to Position Underwater Towed Equipment

There are three main ways to determine the position of underwater towed equipment:

- Install an acoustic positioning system on the towing vessel hull like an USBL and install an acoustic transponder on the towed body.
- Tow a buoy equipped with an acoustic positioning system and a GNSS, or any other positioning system, and install an acoustic transponder on the towed body.
- Tow a specially designed buoy so that it is barely at the surface, so as to be immune from the wind, equipped with a GNSS positioning system for example. It is towed at the same distance from the vessel as the towed body and if it can be assumed that the current is the same at the towed body depth and at the towed buoy depth, then the towed buoy position is a good estimate of the towed body position.

IX. Steering the Vessel

As seen earlier, it is more efficient to steer the vessel automatically [14] when there is a source steering device. Here is a new method to steer a vessel that works both with and without a local steering device.

One of the problems this method solves is where to steer the vessel so that an acoustic source or any other towed body, lying, for example, 500 m behind the vessel, follows a given pre-plot track, within 10 m or less, depending on the conditions, even if the wind and the current change.

Of course, in the case of a very sharp current change, there is no possible track for the towing vessel that keeps the acoustic source on the pre-plot around the sharp current change. Obviously with a 5 knots perpendicular current, a 5 knots vessel cannot sail along its track. Every marine seismic prospector has seen a vessel sailing backward other the ground in strong sea currents.

Fig. 2 represents a vessel V towing a source AS and 4 streamers. The source is towed along the blue planned track Ts. The speed over the ground, Vg is the sum of the water speed Vw and the current C. The water speed is the vessel speed Vs affected by a crab angle due to the wind. In the example of Fig. 2, the crab angle is constant, the vessel speed is constant and the current is constant.

While the vessel is following the track Tv, the acoustic source is following Ts. So for the source to follow the track Ts, the vessel has to have the right heading h that takes into account the crab angle and the current effect so that the ground speed is aligned with the Ts track azimuth, and she has to sail at an offset from the Ts line.

The autopilot PID finds the right heading h and the navigator has to determine the right offset to the pre-plot track at which to position the vessel.

One way to do it is to have a complex hydro-dynamical model and real time current measurements. But well, navigators are able to steer a vessel without real time current measurements and without building complex hydro-dynamical models in their minds, and so there is a simpler way to do it. The method chosen here is based on a "caterpillar" model where the source AS is following, in the water referential, the path of the vessel. This model assumes that the pre-plot lines are almost straight lines, which is usually the case.

The offset is determined by comparing the past vessel position with the current acoustic source position as shown on Fig. 3. This offset is then applied to the pre-plot track to determine the command to send to the autopilot.

This is very different from the method exposed in the patent [15]. In that patent, they try to coordinate the vessel movement and the steered spread element steering and they do so by using a force model to determine the interaction. In the method presented here, the towed spread and vessel steering methods are de-correlated from each other and the effect of the current is corrected without the use of a force model or without measuring it.

It is far simpler and more effective.

X. Conclusion

The high accuracy of the GNSS systems and of RGPS (Relative Global Positioning System) allows a new method to steer a vessel in order for the towed equipment to follow a close to linear pre-determined track over the ground. This method relies on the comparison over time of the past track of the vessel with the current position of the steered equipment to determine an offset that is used to steer the vessel using a common autopilot PID controller. The offset is actually relative to the current speed vector and the vessel water speed.

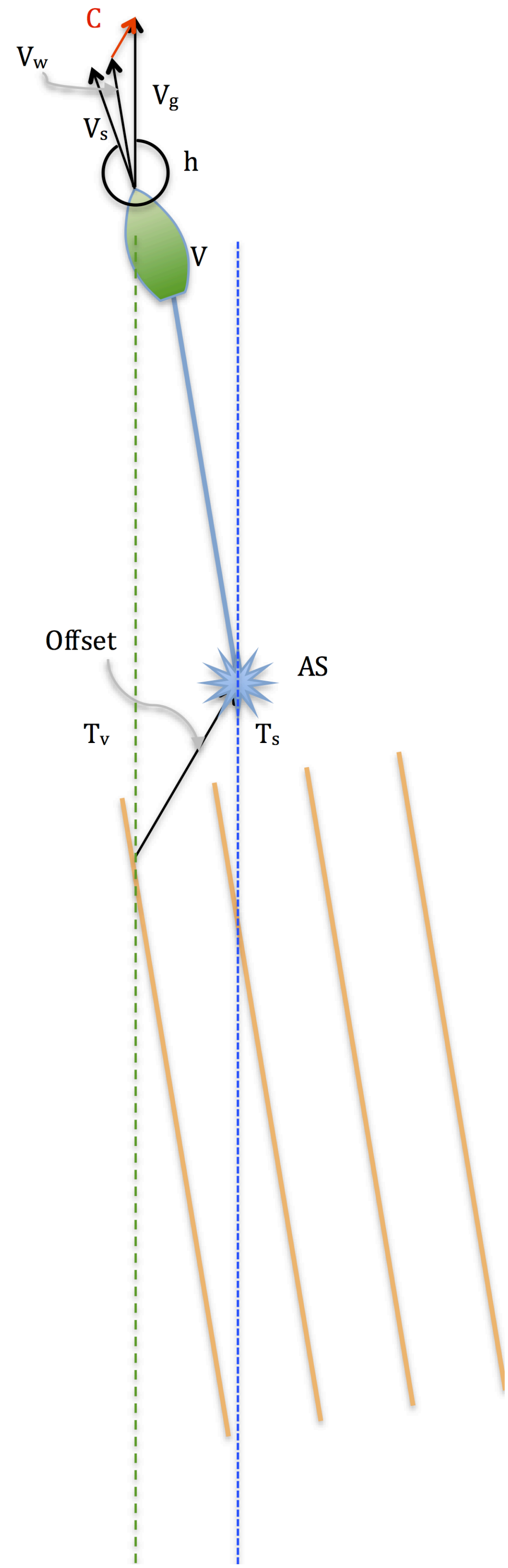

Fig. 2. A seismic vessel V is towing a seismic spread comprising 4 streamers and an acoustic source AS. The vessel heading is h and its speed Vs. Because of the wind, the water speed Vw is different from the vessel speed. The vessel speed on the ground is Vg. With current, the spread is towed on a path over the ground Ts at an offset from the vessel path over the ground Tv.

REFERENCES

[1] International Association of Oil & Gas Producers, "An overview of marine seismic operations," Report No 448, April 2011.

[2] "Execution of marine time-lapse 3D projects: 4D acquisition," a publication of Petroleum Geo-Services, Tech link Vol. 11 No. 5, June 2011.

[3] "Execution of marine time-lapse 3D projects 3 of 4: 4D Processing," a publication of Petroleum Geo-Services, Tech link Vol. 11 No. 7, October 2011.

[4] P. Austad, P. Canter, O. Hodnebo, and W. Olafsen, "Marine seismic cable steering and computerized control systems," SEG Technical Program Expanded Abstracts 2000: pp. 61-63. doi: 10.1190/1.1816141.

[5] G. Brown and J.O. Paulsen "Improved marine 4D repeatability using an automated vessel, source and receiver positioning system," in first break volume 29, November 2011 pp.49-58.

[6] E. Storteig, M. Howlid and R. Singh, "Active steering for marine sources," US patent # US7415936.

[7] H. Tonchia and F. Simonnot, "Steerable source systems and method," US patent # US8891332.

[8] M. Howlid and R. Singh, "Active steering for marine seismic sources," US patent # US8547782.

[9] R. Toennessen and J. M. Soerli, "Systems and methods for steering seismic arrays," US patent # US7577060

[10] "Innovations in marine operations" a publication of Petroleum Geo-Services, Tech link Vol. 8 No. 2, February 2008

[11] H. Tonchia, "Controller and method for steering sources," EP patent # EP2605048.

[12] S. Buizard et al., "Ekofisk Life of Field Seismic - 4D Processing," 75th EAGE Conference doi 10.3997/2214-4609.20130425

[13] A. Vesin, and H. Tonchia, "A rigging of a USBL transceiver for use on a seismic vessel," Oceans - San Diego, 2013, pp.1,3, 23-27 Sept. 2013

[14] H. Tonchia and T. Moulinier, "Device And Method For Steering Seismic Vessel" international Patent Cooperation Treaty application # WO2015071491.

[15] K. Welker, and P. Tyler, "Marine Seismic Survey Method and System" EP patent # EP1735641.

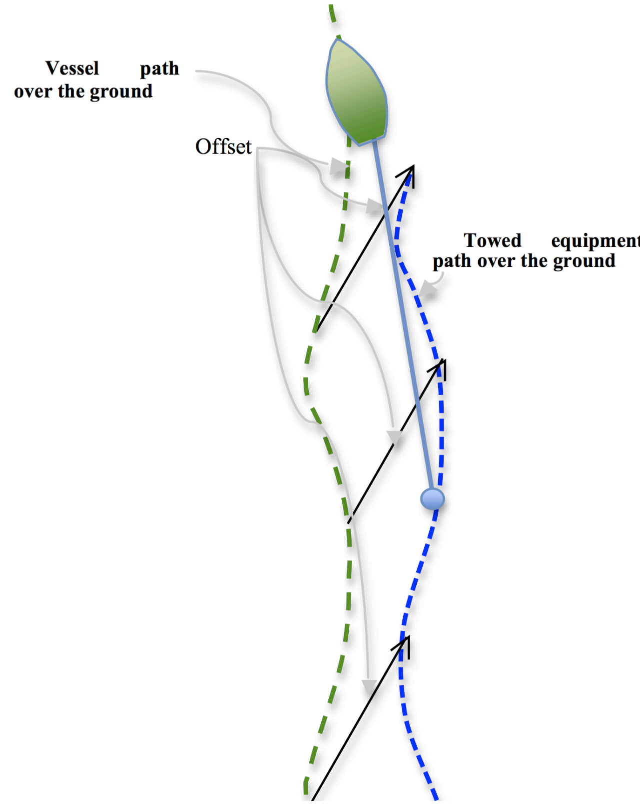

Fig. 3. Determination of the offset which is the vector between the past vessel position and the current towed equipment position. The time in the past being the time it takes for the towed equipment to reach the vessel position at the water speed.