

## Marine Surveying

The present invention relates generally to the field of marine surveying. More particularly, the present invention relates to surveying the structure beneath the seabed using a sub-bottom profiler.

A known system for surveying the structure beneath the seabed using a sub-bottom profiler 15 is shown in Figures 1(a), (b). In this system, a transmitter 20 and a receiver 30 are hull mounted to a survey vessel with the transmitter 20 being upstream with respect to the direction of travel of the survey vessel. The transmitter 20 transmits pulses that travel towards the seabed. Since sound energy is reflected off the boundaries between layers of different densities (and hence acoustic impedance), as a transmitted pulse encounters the boundary between the water and the surface of the seabed, some of its energy is reflected and some of its energy penetrates further into the seabed. As its energy penetrates further into the seabed, further reflections occur as boundaries between layers of, for example, clay, sand and other sediments are encountered. The receiver 30 receives the reflections that allow an image of the structure beneath the seabed to be built up. Figures 2 (a), (b) illustrate the continued operation of the known system. It may be seen that the distance on the seabed between the reflection point of successive pulses,  $dx$ , i.e. the density of the data collected, is governed by the pulse repetition rate and the speed of the survey vessel. For a pulse repetition rate of 450ms and a survey vessel moving at 4 knots (2m/s), the resulting  $dx$  is 0.9m.

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The present invention stems from the inventors' realization that surveying capability is fundamentally constrained by the key physical parameters of the survey, namely the deepest water depth and the penetration beneath the seabed, which place a limit on the maximum pulse repetition rate.

With this in mind, according to a first aspect, the present invention may provide a system for surveying the structure beneath the seabed using a sub-bottom profiler, comprising:

5                   a survey vessel; and

                  a sub-bottom profiler mounted to travel with the survey vessel, the sub-bottom profiler comprising a transmitter for transmitting pulses at a predetermined period between pulses towards the seabed, and a first receiver  
10           and a second receiver for receiving reflections from the seabed of each transmitted pulse;

                  wherein the transmitter and the first and second receivers are mounted along an axis in the direction of travel of the survey vessel and the  
15           transmitter is disposed between the first and second receivers and spaced from each of them by a predetermined separation, and wherein the system is switchable between a high speed mode and a low speed mode.

                  The present invention, by providing a further receiver upstream of the  
20           transmitter, is able to provide enhanced surveying capability without requiring a higher pulse repetition rate (i.e. without requiring a shorter period between pulses). The enhanced surveying capability can be used to survey at high speed or to provide better quality reflection data while surveying at low speed.

25                   Preferably, when the system is in use, the speed of the survey vessel is selected in a high speed mode such that the distance travelled by the transmitter between pulses equals twice the predetermined separation.

                  Preferably, when the system is in use, the speed of the survey vessel is  
30           selected in a low speed mode such that the distance travelled by the transmitter between pulses equals the predetermined separation.

Preferably, the system is switchable between the high speed mode and the low speed mode.

5 The system may further comprise third and fourth receivers that are mounted along said axis, wherein the transmitter is disposed between the third and fourth receivers and spaced from each of them by a second predetermined separation. Through the ability to select between the use of the first and second receivers, on the one hand, and the use of the third and fourth receivers, on the other hand, the user is provided with more options as to survey speed.

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The sub-bottom profiler may be mounted to the hull of the survey vessel or to a body towed by the survey vessel.

15 According to a second aspect, the present invention may provide a sub-bottom profiler intended to be mounted for travel with a survey vessel, the survey vessel having a speed switchable between a high speed mode and a low speed mode, the sub-bottom profiler comprising:

20 a transmitter for transmitting pulses at a predetermined period between pulses towards the seabed, and a first receiver and a second receiver for receiving reflections from the seabed of each transmitted pulse;

wherein the transmitter and the first and second receivers are mounted in fixed relation to one another along an axis with the transmitter being disposed between the first and second receivers and spaced from each of them by a predetermined separation.

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In the context of the present invention, the term “seabed” is to be construed broadly so as to cover the floor of other expanses of water, such as that of an ocean or a lake, regardless of whether the other expanses of water are technically seas or not.

Exemplary embodiments of the invention are hereinafter described with reference to the accompanying drawings, in which:

Figures 1(a), (b) show highly schematic views of the operation of a known sub-bottom profiling system in plan and side view, respectively;

Figures 2(a), (b) illustrate the continued operation of the known system in plan and side view, respectively;

Figure 3 shows a view of a system in accordance with the present invention;

Figures 4(a), (b) show a highly schematic view of the operation of Figure 3 system in plan and side view, respectively; and

Figures 5(a), (b) illustrate the continued operation of the Figure 3 system in plan and side view, respectively.

A system 10 for surveying the structure beneath the seabed in accordance with an embodiment of the invention is shown in Figure 3. The system 10 comprises a survey vessel 12 having a hull 14 to which is mounted a sub-bottom profiler 15. The sub-bottom profiler 15 comprises a frame 16 by which the sub-bottom profiler 15 is mounted to the hull 14. The sub-bottom profiler 15 further comprises a transmitter 20 and first and second receivers 30u,d. The transmitter 20 and the receivers 30u,d are positioned on the frame 16 such that they sit on a single axis of the frame 16 with the transmitter 20 being disposed between the receivers 30u,d and spaced from each of them by a predetermined separation, dx. The frame 16 is mounted to the hull 14 of the survey vessel 12 such that the above-mentioned axis is in alignment with the direction of travel of the survey vessel 12.

Referring to Figures 4(a),(b), the transmitter 20 is operable to transmit pulses at a predetermined repetition rate, i.e. at a predetermined period between pulses, towards the seabed. In one embodiment, the transmitter 20 transmits a frequency modulated chirp pulse. The sweep of the pulse is preferably wideband, for example, 1kHz to 10kHz.

As is visible in Figure 4(b), for each pulse transmitted by the transmitter 20, the upstream receiver 30u receives a reflection of the pulse via an upstream reflection point, called a common mid point, CMP, on the seabed and the downstream receiver 30d receives a reflection of the pulse via a downstream CMP. Each receiver 30u,d comprises a plurality of sensors, which sensors may be hydrophones, and a local controller 32. Each local controller 32 is operable, treating each sensor as part of a sensor array, to perform a sensor array conditioning operation on the raw reflection data. The sensor array conditioning operation typically comprises summing the data recorded at each sensor within the respective receiver 30u,d. The location of the summed output is assumed to be at the center of the respective receiver 30u,d. Each local controller 32 outputs a data stream of conditioned reflection data for that receiver 30u,d.

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The system 10 further comprises a controller 35 which controls the operation of the transmitter 20 and receives the conditioned reflection data from the receivers 30u,d. The controller 35 can form part of the sub-bottom profiler 15 in which case it may be located on the hull 14 as shown, or alternatively, not form part of the sub-bottom profiler 15 itself and be located elsewhere on the survey vessel 15. Based on the received reflection data, the system 10 generates imaging data of the structure beneath the seabed.

In Figures 5(a),(b), the system is shown in use with the speed of the survey vessel being set to a high speed mode in which it travels at, for example, 8 knots (4m/s). S1#, S2#, S3# denote the positions of the transmitter 20 after

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each of the first 3 transmitted pulses. With reference to Figure 5(b), it will be appreciated that the preferred embodiment of the present invention is able to achieve the same resolution of survey as the above-mentioned known system while travelling at twice the speed.

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The system 10 can also be operated in a standard, low speed mode in which it travels at, for example, 4 knots (2m/s). In this mode, each CMP is measured first by the upstream receiver 30u and later by the downstream receiver 30d. Such duplication in the reflection data can be useful in improving the signal-to-noise ratio of the reflection data, and thereby improve the quality of the survey.

The system 10 can also be provided with one or more further upstream/downstream pairs of receivers. In one embodiment, the system 10 further comprises third and fourth receivers that are also mounted along the above-mentioned axis but are each spaced from the transmitter by a second (larger) predetermined separation. A system 10 equipped with one or more further upstream/downstream pairs of receivers provides the user with more flexibility as to the survey speed, since for a given pair of upstream/downstream receivers that are selected (i.e. made active) for a survey their separations from the transmitter determine the speed of the survey vessel in the low speed mode and the high speed mode.

## CLAIMS

1. A system for surveying a structure beneath a seabed using a sub-bottom profiler, comprising:

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a survey vessel; and

a sub-bottom profiler mounted to travel with the survey vessel, the sub-bottom profiler comprising a transmitter for transmitting pulses at a predetermined period between pulses towards the seabed, and a first receiver and a second receiver for receiving reflections from the seabed of each transmitted pulse;

wherein the transmitter and the first and second receivers are mounted along an axis in the direction of travel of the survey vessel and the transmitter is disposed between the first and second receivers and spaced from each of them by a predetermined separation, and wherein the system is switchable between a high speed mode and a low speed mode.

2. A system as in claim 1, wherein a speed of the survey vessel, in the high speed mode, is selected such that the distance travelled by the transmitter between pulses equals twice the predetermined separation.

3. A system as in claims 1 or 2, a speed of the survey vessel, in the low speed mode, is selected such that the distance travelled by the transmitter between pulses equals the predetermined separation.

4. A system as in any preceding claim, wherein the transmitter is operable to transmit a frequency modulated chirp pulse.

5. A system as in any preceding claim, wherein each receiver comprises an array of sensors.

6. The system as in any of claims 1 to 5, further comprising third and  
5 fourth receivers that are mounted along said axis, wherein the transmitter is disposed between the third and fourth receivers and spaced from each of them by a second predetermined separation.

7. A system as in any preceding claim, wherein the sub-bottom profiler  
10 is mounted to the hull of the survey vessel.

8. A system as in any of claims 1 to 6, further comprising a body towed by the survey vessel, wherein the sub-bottom profiler is mounted to the towed  
15 body.

9. A sub-bottom profiler intended to be mounted for travel with a survey vessel, the survey vessel having a speed switchable between a high speed mode and a low speed mode, the sub-bottom profiler comprising:

20 a transmitter for transmitting pulses at a predetermined period between pulses towards the seabed, and a first receiver and a second receiver for receiving reflections from the seabed of each transmitted pulse;

wherein the transmitter and the first and second receivers are  
25 mounted in fixed relation to one another along an axis with the transmitter being disposed between the first and second receivers and spaced from each of them by a predetermined separation.

10. A sub-bottom profiler as in claim 9, further comprising a frame to which the transmitter and the first and second receivers are mounted in fixed relation to one another.