

**METHOD FOR DETERMINING THE LOCATION OF A DETONATOR IN A
WIRELESS NETWORK OF ELECTRONIC DETONATORS, METHOD FOR
PROGRAMMING A BLAST PLAN AND CORRESPONDING FIRING SYSTEM.**

The invention relates to a method for determining the location of a detonator in a wireless network of electronic detonators.

It also relates to a method for programming a blast
5 plan.

It also relates to a firing system comprising a wireless network of electronic detonators.

A detonator here comprises for example a charge, in particular a pyrotechnic charge, and a communication module,
10 for example a bidirectional communication module.

Here, a wireless network of electronic detonators means a set of detonators that are not connected by electrical wires to each other or to an external unit, for example such as a network hub.

15 A network hub designates a piece of electronic equipment configured to coordinate radio communications between various communication modules. It manages a protocol.

The invention has a use in the field of pyrotechnic initiation, in any sector in which a network of at least one
20 electronic detonator must conventionally be implemented.

Typical examples of use relate to mining, quarrying, seismic exploration, or the construction and public works sector.

During the installation of a firing system on a work
25 location or site, each electronic detonator of a network of at least one electronic detonator is installed in a location arranged to receive it.

Such a location is for example a drilled hole, in a floor or a wall in particular.

30 In practice, an operator positions an electronic detonator in the location provided for this purpose.

In order to implement a firing of a network of several electronic detonators, it is useful to know the position of each electronic detonator. Knowing the position of each detonator is mainly necessary in order to program a firing delay associated with at least one of the detonators and thus establish the firing sequence.

To know the position of the electronic detonators in a work site, the geographic coordinates of each electronic detonator can be collected, for example by a GPS receiver device. A GPS device can be implanted on the detonators and/or on a programming tool, for example such as a programming console. If it is implanted on the programming tool, it is the position of the operator, holding the programming tool in their hand, which is valid, that is to say which is equated with the position of the detonator in question. However, the presence of a GPS receiver device associated with each electronic detonator and/or with the programming tool to collect geographic coordinates of electronic detonators can generate significant costs, and/or significant times of presence of the operator in the field to implement this collection.

In addition, absolute positioning is not required for blast operations; a relative topology of the detonators is often sufficient.

Furthermore, such a firing system with GPS is difficult to use, or even cannot be used, on certain terrain, such as underground terrain.

The correct operation of this type of firing system further depends on the availability (reception) of the satellites dedicated to the geolocation system used.

The goal of the present invention is to at least partly overcome the aforementioned disadvantages further leading to other advantages.

For this purpose, according to a first aspect, a method for determining the location of a detonator in a wireless

network of electronic detonators is proposed, the method comprising:

- A step of transmitting a signal by the detonator, referred to as the transmitting detonator;
- 5 - A step of receiving the signal by at least one other detonator of the network, referred to as the receiving detonator, different from the transmitting detonator;
- A step of calculating a distance between the transmitting detonator and the receiving detonator according to the power of the signal that has been received by the receiving detonator.
- 10

Thus, a detonator, for example at least one communication module of the detonator, whether it is on the surface or in a hole, communicates with at least one other
15 detonator of the network, for example with a communication module of the other detonator.

The signal emitted by the transmitting detonator comprises for example an electromagnetic signal, for example a light signal or a radio signal, or a mechanical signal, or
20 an acoustic signal, for example such as an ultrasonic signal.

This can be a light signal if all the detonators of the set comprise a module on the surface.

The step of calculating the distance between the transmitting detonator and the receiving detonator can
25 comprise a step of estimating the distance, or even of estimating an order of magnitude of the distance between the transmitting detonator and the receiving detonator.

According to the situations, a precise determination of the distance, i.e. a determination down to the centimetre,
30 may be unnecessary.

The implementation of such a method thus allows to avoid an operator having to move among the detonators of the network to identify their position, and thus allow their programming.

35 Indeed, it is usually different operators who install a detonator and program it.

Via such a method, once the detonator is deployed and installed, whether the at least one detonator comprises a module on the surface or at the bottom of a hole, the programming can then be transparent for an operator who has
5 to carry it out.

Indeed, a transmitting detonator sends a signal, for example such as a radio wave. At least one other detonator, i.e. a receiving detonator, receives the signal.

Depending on the power of the signal received by the
10 receiving detonator, it is then possible to determine the distance between the transmitting detonator and the receiving detonator.

The attenuation of the signal is thus used to determine the distances of each detonator relative to other detonators
15 in the network.

For example, the steps of the method are implemented for each of the detonators in the wireless network of detonators.

That is to say that each of the detonators in the
20 network is, in turn, a receiving detonator.

Thus, the same detonator can be transmitting and receiving, according to a state of the method.

By triangulation, it is possible to know the position of each detonator in relation to neighbouring detonators in
25 the network of detonators.

For example, the network comprises at least three detonators, among which two detonators are transmitting detonators, which are configured to each transmit a signal, and one detonator, distinct from the two transmitting
30 detonators, is a receiving detonator, which is configured to receive the signal transmitted by each of the transmitting detonators.

In one exemplary embodiment, the method comprises a step of comparing the received signal to a theoretical signal.

In a specific exemplary embodiment, the theoretical signal, to which the received signal is compared, is the transmitted signal.

For example, the method can comprise a step of comparing
5 at least one value of the power of the signal received by the receiving detonator to a theoretical power value of the signal transmitted by the transmitting detonator.

For example, given a rate of power loss per meter of distance between the transmitter and the receiver in the
10 surrounding environment (for example in dB/m (decibels per meter)), it is thus possible to determine a relative position between the transmitter and the receiver.

In one exemplary embodiment, the signal transmitted by the transmitting detonator comprises an identification
15 sequence of the transmitting detonator transmitting the signal.

In particular, the signal received by the receiving detonator comprises the identification sequence of the transmitting detonator having transmitted the signal.

20 Such a method further allows to avoid adding a component in a detonator since each detonator is generally already configured to communicate with a network hub, by radio or optical signal for example.

As soon as one of the detonators in the network is
25 turned on, it enters into the method for determining its location.

For example, the method comprises, prior to the step of transmitting a signal, a step of placing each detonator of the network at a theoretical location.

30 For example, the method comprises a step of turning on each detonator, for example at least one communication module of each detonator, for example a step of powering on.

For example, the method comprises a step of communication between the transmitting detonator and the
35 network hub.

In one exemplary embodiment of the method, the signal transmitted by the transmitting detonator comprises a signal for communication of the transmitting detonator with the network hub.

5 For example, the step of communication between the transmitting detonator and the network hub comprises the step of transmitting a signal by the transmitting detonator.

In one exemplary embodiment, the receiving detonator picks up the signal for communication between the
10 transmitting detonator and the network hub.

In one exemplary embodiment, each detonator of the network also receives the communications transmitted between other detonators of the network and the network hub.

In other words, each detonator in the network picks up,
15 intercepts, the communications sent between the other detonators in the network and the network hub.

The signals are processed, analysed, in a computing unit.

In one exemplary implementation, the computing unit is
20 located in the receiving detonator.

In one exemplary embodiment, the signals are processed externally; the computing unit is then located in a unit different from any detonator, called external unit, for example in the network hub, or in any other electronic unit.

25 Such a step of determining the location of each detonator implemented externally allows to avoid having available an additional computing power or memory in the detonator itself; all the information can be sent together or gradually to the external unit.

30 For example, the method can then comprise a step of transmitting, by the receiving detonator, at least one piece of information representative of the received signal, to the external unit.

The at least one piece of information representative of
35 the received signal can comprise the entirety of the received signal.

For example, the external unit can receive the at least one piece of information representative of the signal received from each of the detonators of the network, and then implements the calculation step based on all the
5 information received.

According to one exemplary embodiment, the at least one representative piece of information comprises the at least one value of the power of the signal received by the receiving detonator.

10 According to one exemplary embodiment, the at least one representative piece of information comprises the identification sequence of the transmitting detonator.

According to one exemplary embodiment, the transmission step comprises a sub-step of sending an identification
15 sequence of the receiving detonator, for example to the external unit.

In an exemplary embodiment of interest, the external unit is the network hub.

For example, an algorithm for locating each of the
20 detonators of the network is implemented in the receiving detonator or in the external unit, for example in the network hub.

Thus, for example, the comparison step can be implemented by the receiving detonator, or by the external
25 unit.

The step of calculating the distance can be implemented by the receiving detonator, or by the external unit.

Each receiving detonator can transmit only the received power value associated with the identification sequence of
30 the transmitter, as well as the identification sequence of the receiving detonator that transmitted this information.

Only the received signal power is useful for calculating the distance between the transmitter and the receiver, but the identification sequence of the transmitter and the
35 identification sequence of the receiver are of interest for identifying a link between the transmitter and the receiver

in question out of all the transmitter-receiver pairs of the detonators of the network to be mapped, in particular if the processing is implemented in a unit external to the network, for example by the network hub.

5 For example, the method comprises a step of recording, by the receiving detonator, the at least one piece of information representative of the received signal.

 For example, the recording is at least temporary, for example until the at least one piece of information has been
10 transmitted to the external unit.

 In a specific example, the at least one piece of information representative of the received signal that is recorded is the power of the received signal.

 For example, the method comprises a step of controlling
15 the transmission of the at least one piece of information representative of the signal received by the receiving detonator to the external unit.

 Such a control step is for example initiated by the external unit.

20 For example, if a transmission control step is implemented, for example after a request from the external unit, the method comprises the step of transmitting at least one piece of information representative of the signal received by the receiving detonator, which optionally
25 includes the sub-step of sending an identification sequence of the receiving detonator.

 The receiving detonator can however process at least one piece of information representative of the received signal itself, according to the power of the received signal,
30 and transmit to the external unit the calculated distance value.

 For example, the receiving detonator can implement the step of calculating the distance between the transmitting detonator and the receiving detonator according to the power
35 of the received signal, itself, and transmit to the external unit the calculated distance value.

Optionally, the transmission of the calculated value can then be accompanied by the identification sequence of the transmitting detonator, or even by the identification sequence of the receiving detonator.

5 The external unit thus receives, for example, information representative of the received signal for each receiving detonator of the set (that is to say each of the detonators of the set, as a receiver).

The information is thus centralised.

10 At least a part of the calculations, or even all of the calculations, are thus carried out by a piece of equipment other than the detonators.

Once the topology of the set is known, i.e. the location of each of the detonators in the network of detonators, a
15 programming operation is easily implemented, for example in a conventional manner, for example manual or automated.

A method as described above allows to know at least a relative topology of the detonators of a network of detonators.

20 Knowing the relative topology is sufficient in some cases.

Otherwise, in order to determine an absolute topology, the method comprises for example a step of identifying the absolute position of at least one first element of the firing
25 system.

The firing system here comprises at least the network of detonators, and preferably an external unit, for example at least the network hub, or even also a communication relay, and/or a firing console.

30 An element of the firing system is therefore for example one of the detonators of the network, or the unit external to the network, for example the network hub, or the communication relay, or the firing console.

Knowing the absolute position of a single element allows
35 at least to anchor the topology of the network in a known coordinate system.

For example, the method further comprises a step of identifying the absolute position of at least one second element of the firing system, the second element being different from the first element.

5 It is then possible to know the absolute position of the network, since the absolute position of a first element and of a second element allows to know an orientation of the network on the ground for example (rotation about an axis "z").

10 According to another aspect, a method for programming a blast plan is proposed, comprising:

- The steps of a method for determining the location of a detonator in a wireless network of electronic detonators, comprising all or part of the features described above; and
- 15 - A step of programming a firing delay associated with the detonator according to its location.

According to another aspect, a firing system configured to implement a method for determining the location of a detonator as described above is also proposed.

20 For example, such a firing system comprises a wireless network of electronic detonators, each detonator in the network comprising a transmitter configured to transmit a signal, and at least one receiver configured to receive a signal transmitted by another detonator of the network, the
25 system further being configured to calculate a distance according to a power of a signal received by the detonator.

For example, an element of the system is configured to calculate the distance between a transmitting detonator and a receiving detonator according to a power of a signal
30 received by the receiving detonator.

For example, the firing system further comprises a unit external to the network of detonators.

In other words, the external unit is distinct from any detonator in the network.

35 An element of the firing system is therefore for example one of the detonators of the network, or the external unit.

For example, each detonator is further configured to transmit at least one piece of information representative of the signal that it has received to the external unit.

According to another aspect, a use of a signal power
5 loss as a function of the distance between a transmitter and a receiver to identify a location of a detonator in a wireless network of electronic detonators is also proposed.

For example, a polarisation of the signal, and/or a signal phase could nonetheless also be used to improve the
10 location accuracy.

Such a method can thus have many uses, for example such as:

- A relative positioning (topology): which is a minimum possibly obtained with a method as described above. The
15 detonators can simply be represented spatially without a scale (representation in rows/columns). Since the distances are measured during the process, the topology can be scaled, and the detonators are then represented in space (map).

- An absolute positioning: if at least two elements of
20 the system (for example a detonator, or an external unit) can provide their absolute position (for example GPS), the complete topology can be positioned in an absolute reference frame.

Alternatively, at least two elements of the system can
25 each be placed at a reference location known to an operator, and the discovered topology is then also positioned in an absolute reference frame.

The invention, according to one exemplary embodiment, will be well understood and its advantages will become more
30 apparent upon reading the following detailed description, given by way of example and in no way limiting, with reference to the appended drawings wherein:

figure 1 schematically shows an exemplary embodiment of a firing system;

figure 2 is a block diagram illustrating a method for locating a detonator according to an embodiment of the invention; and

figure 3 is a block diagram illustrating a method for programming a blast plan according to an embodiment of the invention.

Identical elements shown in the aforementioned figures are identified by identical reference numerals.

Figure 1 illustrates a firing system 1 which is deployed on a terrain 2.

The firing system 1 mainly comprises a wireless network of electronic detonators 10, and at least one external unit 11.

Here, a wireless network of electronic detonators means a set of electronic detonators that are not connected by wires to each other or to an external unit, such as a network hub.

The wireless network of detonators 10 comprises at least one electronic detonator 101, and generally at least two electronic detonators 101, for example ten or even several tens of electronic detonators.

Each electronic detonator 101 of the network 10 is installed at a location arranged to receive it on the terrain 2.

Each detonator 101 comprises for example a pyrotechnic charge 102 and a communication module 103.

In the present exemplary embodiment, the communication module 103 is connected to the charge 102 by at least one electrical connection cable.

The terrain 2 here comprises holes 20, at the bottom of which the charge 102 is disposed.

The communication module 103 is here disposed at the outlet of the hole 20, for example on the surface of the terrain 2.

According to another exemplary embodiment, the communication module is configured to communicate through a

wall; it can then for example be disposed at the bottom of the hole, with the charge 102. A system comprising such a detonator and a "booster" (that is to say an explosive amplifier) can be designated "primer" as opposed to a simple
5 detonator, since it thus also encompasses the explosive amplifier. A simple string can be used to lower the charge 102, or optionally the primer, into the hole 20 and hold it in place.

In the present description, the communication module
10 103 is a module for communication by radio signal (which allows communication with a network hub for example, whether the module is on the surface or in a hole), but this could be any other type of communication, for example by any electromagnetic signal, for example a light signal, or by a
15 mechanical signal, for example an acoustic signal, for example such as an ultrasonic signal, according to the arrangement of the module.

The firing system 1 further comprises here at least one computing unit.

20 In a specific embodiment, the computing unit is comprised in the external unit 11 as shown here, i.e. distinct from a detonator. However, it could be integrated into a detonator.

The computing unit of the firing system 1, when it is
25 external and distinct from a detonator, is for example comprised in the network hub. It could otherwise be integrated into a firing console for example.

The network hub is configured to at least transmit a signal for communication with a detonator 101.

30 In the present example, the communication signal is a radio signal.

In quarries and mines, a firing sequence is required to control the order in which the detonators (rows of holes) are triggered. In the case of electronic initiation, it is
35 therefore necessary to associate a delay (in milliseconds)

of the firing sequence with each detonator. This is the programming operation.

For this purpose, the network hub is configured to communicate with all the detonators 101.

5 The network hub, by order of a firing console, can generate a series of firing commands.

 The network hub is in particular configured to associate a firing delay individually with each electronic detonator 101, according to its location. This common firing order
10 allows to synchronise the countdown of the firing delay for all the electronic detonators in the network. Upon reception of the firing order, each electronic detonator manages the countdown of the specific firing delay associated with it, as well as its own firing.

15 The firing console is generally located at a distance from the network 10 and the network hub.

 The firing console is in particular configured to transmit a firing order, to the network hub.

 At least to communicate with the network hub, each
20 detonator 101 of the network, and in particular here the communication module 103, comprises a transmitter configured to transmit a signal, and at least one receiver configured to receive a signal.

 The programming is a time-consuming operation, which
25 can further take place in a difficult environment (extreme temperature, presence of a hazardous substance, etc.).

 An operation of programming an electronic detonator consists in assigning a delay to it according to its location on the terrain.

30 The programming operation is thus resolved as soon as the location of each detonator (generally identified by its unique identifier) is known.

 When it is done manually, this operation remains time-consuming and error-prone since it relies on the operator
35 who must associate the correct delay or connect (or activate) the detonators in the correct order.

To make the programming operation more reliable and more efficient, the piece of programming equipment can be equipped with a positioning sensor (for example GNSS) in order for the correct delay to be automatically assigned
5 according to the determined position of the detonator. This methodology still has the disadvantage of requiring a costly sensor (differential GNSS) to obtain the necessary accuracy, with potentially long initialisation times (search for the satellites), but above all it always depends on an external
10 signal (satellites) which can not be available (or sufficiently available) or be disturbed by reflections on rock walls according to the environment.

In order to obtain the location, at least relative, of each detonator 101 in a network 10, the present invention
15 therefore proposes a method based on the measurement of the power of neighbouring signals, for example radio signals in the present description of a specific embodiment.

This method thus provides an autonomous solution to the problem of location. No additional external signal is
20 required, and it does not require equipping the detonators with additional hardware. It can thus be easily adaptable to a wireless network of electronic detonators.

Figure 2 illustrates a specific embodiment of the method for determining the location of a detonator in a wireless
25 network of electronic detonators according to the invention.

The method comprises for example steps S100 as follows.

It comprises, for example, a step S1 of placing each detonator 101 of a network 10 at a theoretical location.

30 It then comprises for example a step S10 of turning on each detonator 101.

Then it comprises for example a step S21 of transmitting a communication signal by each detonator, the detonator transmitting the signal thus being designated as the
35 transmitting detonator.

For example, each detonator (more precisely its communication module) communicates with at least one neighbouring detonator.

5 The communication signal can be a signal for conventional communication, for example with a network hub, or an independent signal.

For example, the method comprises a step S2 of communication between the transmitting detonator and a network hub, the communication step S2 comprising the step
10 S21 of transmitting a signal by the transmitting detonator, the transmitted signal optionally comprising the signal for communication with the network hub.

Each detonator measures the power of the signal that it has received from at least one other detonator in the network.
15 The detonator receiving the signal is thus called the receiving detonator.

For example, each receiving detonator measures or determines an "RSSI" (Received Signal Strength Indication) value, that is to say a measurement of the received power of
20 a radio signal, of at least one other detonator of the network. If the transmission power of the signal is already known by each detonator as a receiver, it is not therefore necessary to transmit this value; otherwise the communication signal can carry this information.

25 According to an option of interest, the method can comprise a step of calculating the distance directly in the receiving detonator; if necessary, the calculation step uses for example the intensity of the received signal (RSSI measurement) and combines it with a theoretical attenuation
30 model.

The estimated distances between detonators of the network (alternatively, some or all of the information, for example the measured information of the RSSI values) are sent to an external unit (for example controlling the network,
35 for example the network hub) which determines the location

of each detonator of the network by cross-checking the measurements.

Well-known location resolution algorithms can be applied.

5 A location for each detonator is thus determined.

The locations can only be relative (topology of the network).

The locations can be given with a confidence index (probability).

10 A map of the network of detonators 10 is thus available.

The external unit 11, for example the network hub, if it is placed near the network of detonators, can be used as a "neighbouring element" of all the detonators 101 during the method. This allows to anchor the relative topology with
15 a reference point, with a view to determining a topology considered as absolute.

This is repeated with at least one second element in order to know the absolute positioning of the network of detonators.

20 The method thus also comprises:

- A step S3 of receiving the signal by at least one other detonator of the network, called the receiving detonator.

- A step S5 of calculating the distance between the
25 transmitting detonator and the receiving detonator according to the power of the signal that has been received by the receiving detonator.

In one exemplary embodiment, the method can comprise a step S4 of transmitting, by the receiving detonator, at least
30 one piece of information representative of the signal received by the receiving detonator, to an external unit 11, which is for example the network hub.

The transmission step S4 can comprise a sub-step S41 of sending an identification sequence of the receiving
35 detonator, to the external unit 11.

The method can also comprise a step S6 of identifying the absolute position of at least one first element, and preferably also of at least one second element, of a firing system which comprises at least the network of detonators.

5 Figure 3 illustrates a specific embodiment of a method for programming a blast plan according to the invention.

 The method comprises for example steps as follows:

 - At least some of the steps S100 of a method for determining the location of a detonator in a wireless network
10 of electronic detonators, for example as described in relation to figure 2; and

 - A step S101 of programming a firing delay associated with the detonator according to its location.

CLAIMS

1. Method for determining the location of a detonator (101) in a wireless network of electronic detonators (10), the method comprising:

5 - A step (S21) of transmitting a signal by the detonator, referred to as the transmitting detonator;

 - A step (S3) of receiving the signal by at least one other detonator of the network, referred to as the receiving detonator;

10 - A step (S5) of calculating a distance between the transmitting detonator and the receiving detonator according to a power of the signal that has been received by the receiving detonator.

2. Method according to claim 1, comprising a step (S6) of identifying the absolute position of at least one first
15 element and of at least one second element of a firing system (1), the firing system (1) comprising at least the network of detonators (10).

3. Method according to claim 1 or 2, comprising, prior to the step of transmitting a signal, a step (S1) of placing
20 each detonator (101) of the network (10) at a theoretical location, and a step (S10) of turning on each detonator.

4. Method according to any one of claims 1 to 3, comprising a step (S2) of communication between the transmitting detonator and a network hub, the communication
25 step (S2) comprising the step (S21) of transmitting a signal by the transmitting detonator, the signal transmitted by the transmitting detonator comprising a signal for communication of the transmitting detonator with the network hub.

5. Method according to any one of claims 1 to 4, wherein
30 the signal transmitted by the transmitting detonator comprises an identification sequence of the transmitting detonator transmitting the signal.

6. Method according to claim 5, wherein the signal received by the receiving detonator comprises the

identification sequence of the transmitting detonator having transmitted the signal.

7. Method according to any one of claims 1 to 6, comprising a step (S4) of transmitting, by the receiving
5 detonator, at least one piece of information representative of the signal received by the receiving detonator, to an external unit (11).

8. Method according to claim 7, wherein the external unit (11) is a network hub.

10 9. Method according to any one of claims 7 or 8, wherein the transmission step (S4) comprises a sub-step (S41) of sending an identification sequence of the receiving detonator, to the external unit (11).

10. Method for programming a blast plan, comprising:

15 - The steps (S100) of a method for determining the location of a detonator in a wireless network of electronic detonators according to any one of claims 1 to 9; and
- A step (S101) of programming a firing delay associated with the detonator according to its location.

20 11. Firing system (1) comprising a wireless network of electronic detonators (10), each detonator (101) of the network (10) comprising a transmitter configured to transmit a signal, and at least one receiver configured to receive a signal transmitted by another detonator of the network (10),
25 the system being further configured to calculate a distance according to a power of a signal received by the detonator.

12. System (1) according to claim 11, comprising a unit external to the network (10) of detonators, and wherein each detonator (101) is further configured to transmit a piece of
30 information representative of the received signal to the external unit (11).

13. Use of a signal power loss as a function of the distance between a transmitter and a receiver to identify a location of a detonator (101) in a wireless network of
35 electronic detonators (10).