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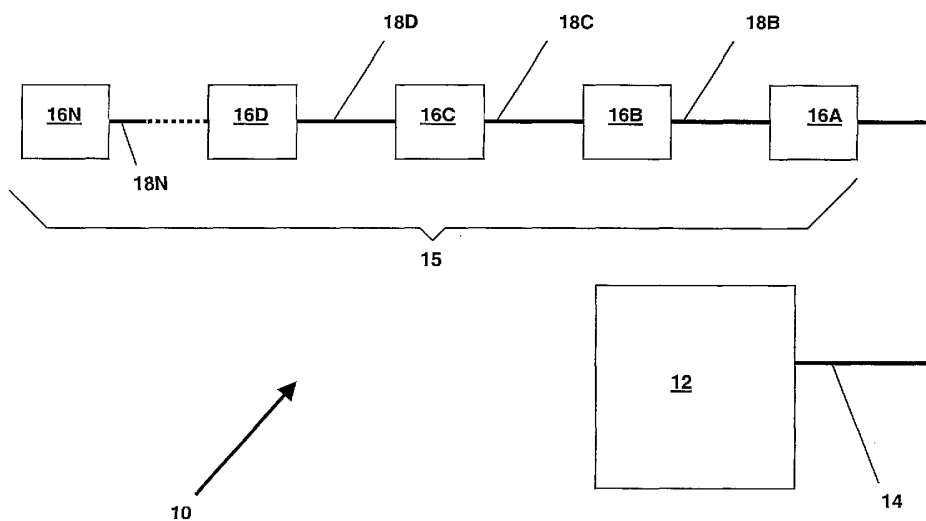
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- (74) Agent: **TOCHER, A., J.**; QinetiQ Ltd, IP Formalities, Cody Technology Park, A4 Building, Room G016, Ively Road, Farnborough, Hampshire GU14 0LX (GB).
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- (71) Applicant (for all designated States except US): **QINETIQ LIMITED** [GB/GB]; Registered Office, 85 Buckingham Gate, London SW1E 6PD (GB).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **HILL, David, John** [GB/GB]; QinetiQ Limited, Winfrith Technology Centre, Room A22/162, Winfrith Newburgh, Dorchester, Dorset DT2 8XJ (GB). **NASH, Philip, John** [GB/GB]; QinetiQ Limited, Winfrith Technology Center, Room A22/162, Winfrith Newburgh, Dorchester, Dorset, DT2 8XJ (GB).

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(54) Title: FIBRE-OPTIC SURVEILLANCE SYSTEM



(57) Abstract: A fibre-optic surveillance system (10) includes a fibre-optic sensor (15) comprising a serial array (15) of fibre-optic point-sensors (16), successive point-sensors being linked by a distributed fibre-optic sensor (18). The system allows the location of intruder events along the sensor to be determined, and provides a reduction in the incidence of false-alarms compared to prior art systems.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

FIBRE-OPTIC SURVEILLANCE SYSTEM

The present invention relates to fibre-optic surveillance systems, particularly fibre-optic perimeter surveillance systems.

5

It is known to use optical fibres as sensing elements to detect pressure, strain etc, with conditions external to an optical fibre being inferred from changes in characteristics, such as amplitude, frequency or polarisation, in light output from the fibre. An example is the pressure sensor described in European Patent
10 number 0 365 062.

One approach to perimeter surveillance is to arrange a single length of optical fibre below ground level around a perimeter to be monitored, and to couple radiation from an LED or laser-diode into the fibre. Pressure on the fibre due to the weight
15 of a person, vehicle or other object crossing a perimeter defined by the fibre causes a change in the amount of radiation back-scattered within the fibre (due to bending of the fibre), and hence the presence of an intruder can be detected. However, such a system has three significant disadvantages, namely (i) the position at which an intruder crosses the perimeter cannot be determined
20 accurately, (ii) a significant false-alarm rate, (iii) no information is given about the nature of the intruding person or object and (iv) an inability to multiplex multiple sensing zones on a single fibre. Alternatively, the transmission of the fibre may be monitored as described in US patent 4 812 645. This type of system has similar drawbacks.

25

Optical fibre interferometric sensors can be used to detect pressure and vibration. When a length of optical fibre is subjected to an external pressure the fibre is deformed. This deformation alters the optical path length of the fibre, which can be detected as a change in phase of light passing along the fibre. As it is possible
5 to analyse for very small changes in phase, optical fibre sensors are extremely sensitive to applied pressure. Such a sensor is described as an interferometric sensor. This high sensitivity allows optical fibre sensors to be used for example, in acoustic hydrophones where sound waves with intensities equivalent to a pressure of 10^{-4} Pa are routinely detectable. Published UK patent application 2 262 803
10 describes an interferometric system having a serial array of distributed fibre-optic sensors, however such a system provides no accurate positional information about an intruder or information relating to the nature of the intruder.

Published UK patent application 2 176 364 discloses a serial array of localised
15 fibre-optic sensors. This system is only able to provide detection if an intruding person, vehicle etc passes one of the localised sensors.

According to a first aspect of the invention, these problems are ameliorated by a fibre-optic sensor array for a surveillance system characterised in that the sensor
20 array comprises a at least two fibre-optic point sensors, in which each pair of successive point sensors are linked by a distributed fibre-optic sensor.

Optical fibre sensors have the advantage that they can be multiplexed without recourse to local electronics. Interferometric sensors can also be formed into
25 distributed sensors with a length sufficient to cover that of typical security zone

perimeters (20-100m). By adopting this hybrid approach of point sensors and interstitial distributed sensors the system benefits from a high detection efficiency.

A second aspect of the invention provides a fibre-optic surveillance system characterised in that the system comprises a fibre optic sensor of the invention
5 connected to an interrogation system adapted to respond to an optical phase shift in at least one sensor of the array due to a force applied to that sensor and to establish the position the position at which said force is applied.

10 The force could be applied by a person, animal, vehicle or other object crossing a path which is under surveillance, with the sensor array being positioned on or near the path, or underneath it.

This provides a low cost, reliable fibre-optic surveillance system which is suitable
15 for perimeter monitoring and which can be highly multiplexed. Remote interrogation is possible so neither local electronics nor local electrical power are required.

The fibre-optic sensor array may be connected to the interrogation system by a
20 fibre-optic cable or alternatively by a transducer and a wire cable.

The fibre-optic point sensors may comprise optical fibre wound into a flexural disc, or may for example be geophones.

25 Alternatively the fibre-optic point sensors may be fibre-optic accelerometers. The need to monitor extremely low levels of vibration in security and seismic survey

has spurred the development of ever more sensitive accelerometers. Fibre optic technology has been applied to this particular field in the form of fibre-optic accelerometers based on interferometric techniques. The compliant cylinder approach to the design of a fibre-optic accelerometer is particularly effective when
5 incorporated in such an interferometer. In one known approach a seismic mass is held in place by two compliant cylinders and around the circumference of each cylinder there being wound a single mode optical fibre, which form the arms of an interferometer. In another approach, a single compliant cylinder loaded with a seismic mass is wound circumferentially with an optical fibre.

10

The distributed fibre optic sensors preferably comprise optical fibre packages for measuring pressure on, or bend, of the distributed sensors.

Preferably, the interrogation system comprises a reflectometric interferometric
15 interrogation system, more preferably the interferometric interrogation system comprises a pulsed reflectometric interferometric interrogation system in which Time Division Multiplexing (TDM) is used to distinguish individual sensors. This is a very efficient multiplexing architecture that can be used with distributed and point sensors. Furthermore wavelength Division multiplexing (WDM) can be used to
20 increasing the number of sensors multiplexed on a single fibre further.

Alternatively, the interferometric interrogation system may comprise a Rayleigh backscatter interferometric interrogation system, with a pulsed Rayleigh backscatter interferometric interrogation system being particularly preferred.

25

A non-Rayleigh backscattering reflectometric system relies upon discrete reflectors between sensors. These are comparatively expensive components, which may add to the cost of the overall system. In contrast, Rayleigh backscattering relies on reflection of light from inhomogeneities in the optical fibre.

5 This removes the need for discrete reflectors, reducing the overall cost of the system. However, the data collected from such a system requires more complex analysis than a reflectometric interrogation system.

A third aspect of the invention provides a method of establishing the position at
10 which an object moving on the earth's surface crosses a closed path, or an open path of fixed length, thereon, characterised in that the method comprises the steps of

- (i) positioning a sensor according to claim 1 on or below said path; and
- (ii) analysing optical signals received from the sensor to establish the
15 position of the object along the path, or the position at which the object has crossed said path.

The optical signals are preferably analysed by measuring the delay between the signals received from adjacent fibre-optic point sensors along the array and
20 combining these signals with the signal from the distributed fibre-optic array linking those fibre-optic point sensors to locate and confirm the said position.

An embodiment of the invention are described below by way of example only and with reference to the accompanying drawing in which schematically illustrates a
25 fibre-optic perimeter surveillance system according to the invention.

In Figure 1, a fibre-optic perimeter surveillance system according to the invention is indicated generally by 10. The system 10 comprises a series of fibre-optic point sensors 16A, 16B, 16C, 16D,, 16N (in this example, geophones) optically linked by a series of distributed fibre-optic sensors 18B, 18C, 18D,, 18N to form a fibre-optic sensor array 15. A data link 14 couples the geophone 16A to an interrogation unit 12. The data link 14 may be a length of optical fibre, so that optical signals are passed to the interrogation unit 12, or alternatively it may comprise a detector which converts optical signals into electrical signals and either a fixed electrical, or wireless, link to the interrogation unit 12.

10

The distributed fibre-optic sensors 18B, 18C, 18D,, 18N each have a physical length of 100m. There are 250 geophones in the array 15, so that the separation of geophones 16A, 16N may be up to approximately 24.9km.

15 Each of the geophones 16A, 16B, 16C, 16D,, 16N comprises approximately 100m of optical fibre wound onto a flexural disc, and is able to measure acceleration and displacement via strain induced in the fibre. Each of the distributed sensors 18B, 18C, 18D,, 18N comprises 100m of optical fibre packaged within a cable and can measure pressure on, or bend of, the cable, also
20 via strain induced on the fibre.

The array 15 may be arranged in any desired configuration, for example it may be arranged around a closed path to provide perimeter surveillance for e.g. a building; alternatively it may be arranged in a linear manner to provide information on the
25 location of a person/object crossing a straight line defined by the array 15.

The system 10 operates as follows. When a person or object crosses a line or perimeter on or underneath which the array 15 is positioned, a force resulting from the person's or object's weight (plus possibly also a force resulting from a change in momentum if there is an impact) is applied to the sensor array. This causes radiation within a distributed fibre-optic sensor corresponding to the location where the person/object crosses to be reflected back to geophone 16A and a corresponding signal giving approximate location is passed to the interrogation unit 12. More particularly the interrogation unit 12 is able to identify that a crossing has occurred somewhere along the length of the array 15. Radiation is also reflected back from the geophones at either end of that distributed sensor, and corresponding signals are also passed to the interrogation unit 12. The interrogation unit 12 carries out triangulation of the signals received from the distributed sensor and the geophones at either end of it to accurately determine the location along the array 15 at which the person/object has crossed on the basis of the time at which signals are received. By using data from both types of sensor, it is possible to provide much more accurate classification of the person/object than is achievable through use of one sensor type alone. Improved classification results in a lower false-alarm rate.

In the example system 10, the point fibre-optic sensors are geophones, however other types of fibre-optic point sensor may be used.

The number of point and distributed sensors may vary according to both the length of a perimeter or path which is desired to be monitored, and the accuracy with which it is desired to locate intruder events. The simplest fibre-optic sensor of the

invention would comprise a single distributed sensor having a point sensor at each end.

Given that the detection range of a person walking using a ground mounted fibre optic accelerometer can be >30m in certain ground types, an array of
5 accelerometers positioned say 40m apart will ensure full coverage of a perimeter.

By comparing signals received on adjacent accelerometers and measuring the time difference between common features on the signal it is possible to accurately
10 calculate the position of the intrusion along the length of the interstitial fibre.

Further temporal and frequency analysis of the accelerometer signals and the signals received from the distributed interstitial sensing cable enable intrusion classification , thereby reducing the system false alarm rate.

15

Suitably, the known distance is between 20m and 50m. The known distance refers to the physical separation of the fibre optic sensors and is defined by the optical path length of the optical fibre between each sensor and the length of fibre used in each accelerometer.

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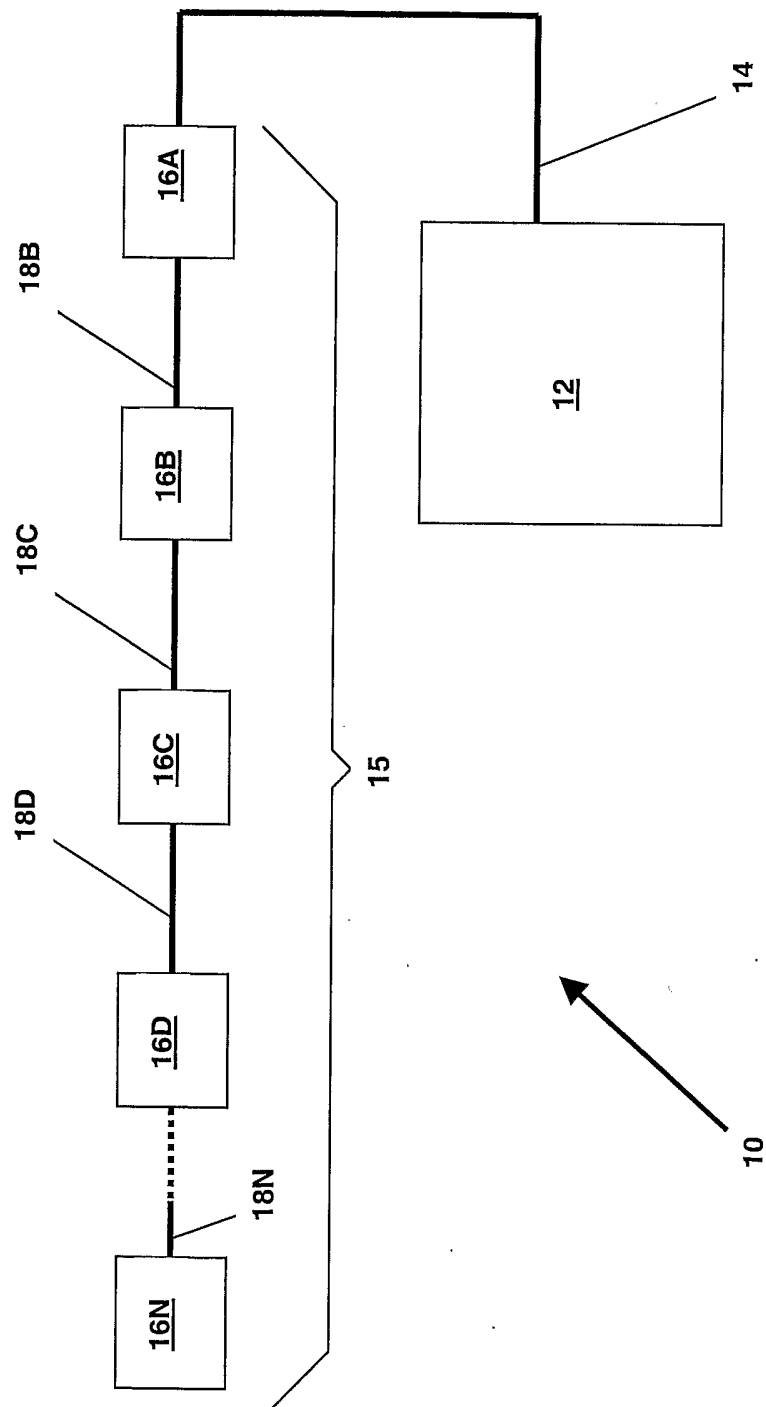
CLAIMS

1. A fibre-optic sensor array (15) for a surveillance system (10) characterised in that the sensor array comprises at least two fibre-optic point sensors (16), in
5 which each pair of successive point sensors is linked by a distributed fibre-optic sensor (18).
2. A fibre-optic surveillance system (10) characterised in that the system comprises a fibre optic sensor array (15) according to claim 1 connected to
10 an interrogation system (12) which is adapted to respond to an optical phase shift in at least one sensor of the array due to a force applied to that sensor and to establish the position at which said force is applied.
3. A fibre-optic surveillance system according to claim 2 wherein the fibre-optic
15 sensor array is connected to the interrogation system by a fibre-optic cable.
4. A fibre-optic surveillance system according to claim 2 wherein the fibre-optic sensor array is connected to the interrogation system by a transducer and a
20 wire cable.
5. A fibre-optic surveillance system according to claim 2 wherein the fibre-optic points sensors comprise optical fibre wound into a flexural disc.
6. A fibre-optic surveillance system according to claim 2 wherein the fibre-optic
25 points sensors are geophones.

7. A fibre-optic surveillance system according to claim 2 wherein each fibre-optic point sensors comprises a fibre-optic accelerometer.
8. A fibre-optic surveillance system according to claim 2 wherein the distributed
5 fibre optic sensors comprise optical fibre packages within a cable to measure pressure on or bend of the cable.
9. The system of claim 2 wherein the interrogation system comprises an interferometric interrogation system.
10. The system of claim 9 wherein the interferometric interrogation system comprises a reflectometric interferometric interrogation system.
11. The system of claim 10 wherein the reflectometric interferometric
15 interrogation system comprises a pulsed reflectometric interferometric interrogation system.
12. The system of claim 11 wherein the pulsed reflectometric interferometric
20 interrogation system employs time-division multiplexing to distinguish individual sensors.
13. The system of claim 2 wherein the interrogation system comprises a Rayleigh-backscatter interrogation system.
- 25 14. The system of claim 13 wherein the Rayleigh-backscatter interrogation system comprises a pulsed Rayleigh-backscatter interrogation system.

15. A method of establishing the position at which an object moving on a surface crosses a closed path, or an open path of fixed length, thereon, characterised in that the method comprises the steps of
- (i) positioning a sensor according to claim 1 on or below said path; and
 - 5 (ii) analysing optical signals received from the sensor to establish the position of the object along the path, or the position at which the object has crossed said path.
16. A method according to claim 15 wherein the optical signals are analysed by
- 10 measuring the delay between the signals received from adjacent fibre-optic points sensors along the array and combining these signals with the signal from the distributed fibre-optic array linking those fibre-optic point sensors to locate and confirm the said position.

Fig 1



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 G01D5/353 G01L1/24 G08B13/186

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 IPC 7 G01D G01L G08B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
 EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category ^o	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5 140 154 A (YUREK AILEEN M ET AL) 18 August 1992 (1992-08-18) column 2, line 3 - line 10	1, 2, 15
A	EP 0 365 062 A (PHILIPS ELECTRONIQUE LAB ; PHILIPS NV (NL)) 25 April 1990 (1990-04-25) cited in the application the whole document	1, 2, 15
A	GB 2 176 364 A (GEN ELECTRIC CO PLC) 17 December 1986 (1986-12-17) cited in the application the whole document	1, 2, 15

Further documents are listed in the continuation of box C. Patent family members are listed in annex.

^o Special categories of cited documents :

<p>*A* document defining the general state of the art which is not considered to be of particular relevance</p> <p>*E* earlier document but published on or after the international filing date</p> <p>*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>*O* document referring to an oral disclosure, use, exhibition or other means</p> <p>*P* document published prior to the international filing date but later than the priority date claimed</p>	<p>*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>*Z* document member of the same patent family</p>
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Date of the actual completion of the international search 5 January 2005	Date of mailing of the international search report 12/01/2005
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Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer De la Cruz Valera, D
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INTERNATIONAL SEARCH REPORT

International Application No

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