



(51) International Patent Classification:

G02B 6/48 (2006.01) H04B 10/2575 (2013.01)

(21) International Application Number:

PCT/US2020/026505

(22) International Filing Date:

03 April 2020 (03.04.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/829,669 05 April 2019 (05.04.2019) US
16/838,105 02 April 2020 (02.04.2020) US

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(81) Designated States (unless otherwise indicated, for every

kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every

kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) Title: AERIAL FIBER OPTICAL CABLE LOCALIZATION USING DISTRIBUTED SENSING

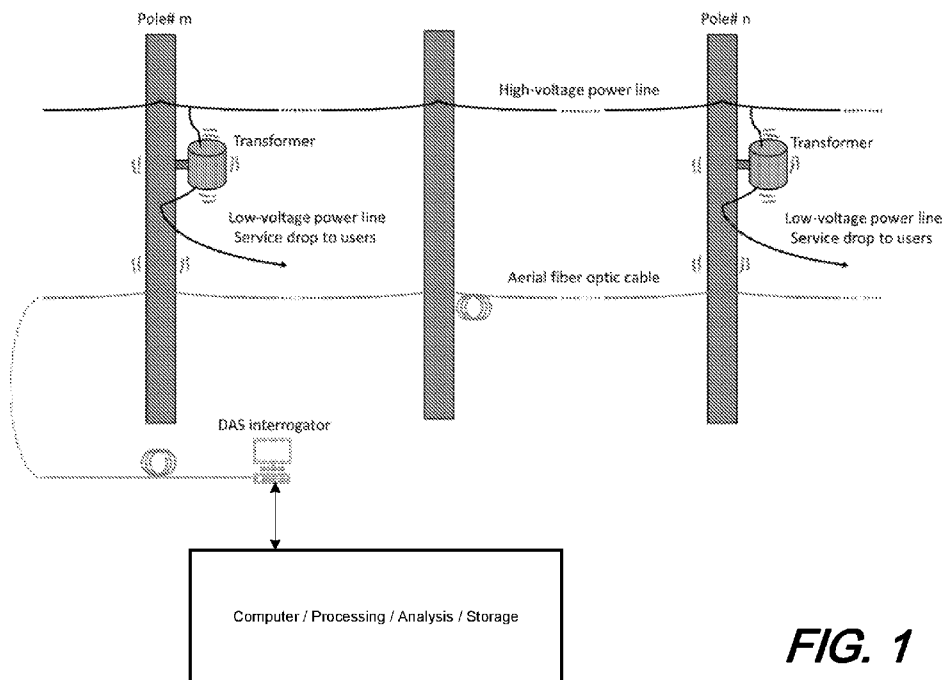


FIG. 1

(57) Abstract: Aspects of the present disclosure describe aerial fiber optical cable localization using distributed acoustic sensing (DAS) that advantageously may determine the locality of electrical transformers affixed to utility poles along with the aerial fiber optical cable as well as any length(s) of fiber optical cable between the poles. Further aspects employ survey manned or unmanned, aerial or terrestrial survey vehicles that acoustically excite locations along the fiber optical cable and associate those DAS excitations with global positioning location (GPS).

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

AERIAL FIBER OPTICAL CABLE LOCALIZATION USING DISTRIBUTED SENSING

CROSS REFERENCE

[0001] This disclosure claims the benefit of United States Provisional Patent Application Serial No. 62/829,669 filed 04/05/2019 and United States Utility Patent Application Serial No. 16/828,105 filed 04/02/2020 the entire contents of which is incorporated by reference as if set forth at length herein.

TECHNICAL FIELD

[0002] This disclosure relates generally to optical communications and optical sensing systems, methods and structures. More particularly, it describes the determination of aerial cable localization using distributed sensing.

BACKGROUND

[0003] As is known aerial fiber optic cables are used to provide data communications services to both residential and commercial sites. And while aerial cables are usually attached to utility poles and exhibit a fixed route, it is nevertheless difficult for telecommunications carriers and service providers to estimate or otherwise determine aerial cable length distributions on a geographic map solely based on pole-to-pole distance(s) and poles' geographic locations – due in part to extra cable loops/coils deployed in the aerial configurations for possible future drop points, branches, and general redundancy.

SUMMARY

[0004] An advance in the art is made according to aspects of the present disclosure directed to aerial cable localization using distributed acoustic sensing (DAS) technology.

[0005] In sharp contrast to the prior art, systems, methods, and structures according to aspects of the present disclosure advantageously achieve aerial fiber optical cable localization using distributed acoustic sensing (DAS) that advantageously determines the

locality of electrical transformers affixed to utility poles along with the aerial fiber optical cable as well as any length(s) of fiber optical cable between the poles. Further aspects employ survey manned or unmanned, aerial or terrestrial survey vehicles that acoustically excite locations along the fiber optical cable and associate those DAS excitations with global positioning location (GPS).

BRIEF DESCRIPTION OF THE DRAWING

[0006] A more complete understanding of the present disclosure may be realized by reference to the accompanying drawing in which:

[0007] **FIG. 1** shows a schematic diagram of an illustrative aerial fiber optic cable arrangement on utility poles along with high-voltage power line(s) and distributed acoustic sensing (DAS) interrogator according to aspects of the present disclosure;

[0008] **FIG. 2** shows a schematic diagram of an illustrative aerial fiber optical cable arrangement on utility poles along with high-voltage power line(s) and distributed acoustic sensing (DAS) interrogator being stimulated by a mobile stimulator according to aspects of the present disclosure;

[0009] **FIG. 3** is a flow diagram illustrating overall process/method according to aspects of the present disclosure; and

[0010] **FIG. 4** is a flow diagram illustrating an additional process/method according to aspects of the present disclosure.

[0011] The illustrative embodiments are described more fully by the Figures and detailed description. Embodiments according to this disclosure may, however, be embodied in various forms and are not limited to specific or illustrative embodiments described in the drawing and detailed description.

DESCRIPTION

[0012] The following merely illustrates the principles of the disclosure. It will thus be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the disclosure and are included within its spirit and scope.

[0013] Furthermore, all examples and conditional language recited herein are intended to be only for pedagogical purposes to aid the reader in understanding the principles of the disclosure and the concepts contributed by the inventor(s) to furthering the art and are to be construed as being without limitation to such specifically recited examples and conditions.

[0014] Moreover, all statements herein reciting principles, aspects, and embodiments of the disclosure, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.

[0015] Thus, for example, it will be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the disclosure.

[0016] Unless otherwise explicitly specified herein, the FIGs comprising the drawing are not drawn to scale.

[0017] We begin by noting once more that systems, methods, and structures according to aspects of the present disclosure advantageously and inventively employ distributed acoustic sensing (DAS) to measure/determine locations with specific acoustic excitations along an aerial fiber optic cable. Generally, by associating the measured locations along the aerial cable and the geographic locations of those acoustic excitations, the aerial cable route and length distribution may then be geographically mapped. As used

herein, the “location along the aerial cable” is the aerial cable length between a location under test and a DAS interrogator connected to and communicating with the aerial cable.

[0018] FIG. 1 shows a schematic diagram of an illustrative aerial fiber optic cable arrangement supported on utility poles along with high-voltage power line(s) and distributed acoustic sensing (DAS) interrogator according to aspects of the present disclosure;

[0019] As may be observed from that figure, high-voltage power lines are shown as supported on utility poles – a column or post used to support overhead (aerial) power lines and various other public utilities such as electrical cable, fiber optic cable, and related equipment such as transformers and street lights. A utility pole may be referred to as a transmission pose, telephone pole, telecommunication pole, power pole, hydro pole, telegraph pole, or telegraph post, depending upon its application and particular language dialect in an area in which it is installed.

[0020] Shown further in that figure are transformers that convert a relatively high-voltage to a lower-voltage for the purposes of electrical power distribution. The transformers – while shown as bring mounted or suspended on the utility poles, may sometimes be installed nearby on the ground, with connecting power cables dropped from the poles to the transformer(s).

[0021] As those skilled in the art will appreciate, due to magnetostriction effect(s), the transformers intrinsically vibrate and generate mechanical disturbances (i.e., sounds/noise) at specific frequencies. Such sounds/noise/vibrations may be transmitted – via the utility pole and/or connecting cable – to the aerial cable attached to the pole(s).

[0022] Note that a fundamental frequency of the noise from the transformer is substantially twice that of the alternating current (AC) frequency, i.e., 12Hz noise for 60 Hz AC power, or 100 Hz noise for 50 Hz AC power. Therefore, by detecting the peak locations of the transformer vibration frequencies (e.g., 120Hz or 100Hz) along the aerial cable, the poles supporting (hosting) both the transformer and the aerial cable can be

located along the aerial cable. Combining the geophysical location information of these poles and the aerial cable lengths measured between these poles, the aerial cable route and length distribution may be geographically mapped.

[0023] Advantageously, our inventive methodology may be applied to existing power/pole/telecommunications/optical fiber cable installations to provide such functionality. Operationally, the overall methodology may be described by:

1. Providing a distributed acoustic sensing (DAS) interrogator and coupling same to an existing aerial fiber optic cable;
2. Using DAS, continuously monitor an acoustic signal along the entire aerial fiber optic cable;
3. Using a real-time bandpass filter centered at 120Hz (or 100Hz if AC frequency is 50 HZ), continuously filter the DAS signal other than 120 Hz;
4. From the filtered DAS signal, determine constantly present signal peaks and their representative location(s) along the aerial cable measured by DAS.
5. Determine, from the constantly present signal peaks and their representative locations, the geophysical locations of the poles with transformers.

[0024] We note that with respect to the above methodology, it may be observed that as shown in **FIG. 1**, pole m and pole n have transformers suspended therefrom. As such, DAS can detect two peaks along the aerial optical cable, one each corresponding to the individual transformers. One peak – generated by transformer on pole m – is illustratively located at x meters from DAS interrogator. The other peak – generated by transformer on pole n – is illustratively located at y meters away from the DAS interrogator. Since these peaks are excited/produced by the poles with transformers, the geophysical locations of these poles with transformers are the geophysical locations of the peaks along

the length of aerial cable. By matching the geophysical locations of these poles suspending the transformers responsible for producing these peaks with the peak locations along the aerial cable, the aerial cable length(s) between these poles are obtained. For example, in **FIG. 1**, the aerial cable length between pole m and pole n is $(y-x)$ meters.

[0025] Accordingly, the aerial cable route and length distribution between these poles with transformers may be geographically mapped. Those skilled in the art will of course appreciate that the above method is performed on a digital computer, that may be programmed to control the DAS operation, receive, and filter the returned DAS signals, store geolocations of the poles and determine any associations between the returned DAS signals and the geolocations of those poles as well as determine length(s) of fiber between the poles.

[0026] Advantageously, we now disclose another method according to aspects of the present disclosure whereby we employ a survey vehicle – manned or unmanned – aerial (drone) or terrestrial (automobile) – equipped with an acoustic signal generator e.g., a speaker, as an acoustic excitation source. The operation setup and principles are schematically illustrated in **FIG. 2**.

[0027] Operationally, a survey vehicle with acoustic signal generator (e.g. speaker) and GPS logger is used as a moving acoustic excitation source. Note that while the survey vehicle is shown as a terrestrial/ground vehicle (automobile), it may also be performed by aerial drone. Either type of survey vehicle may advantageously be manned or unmanned. Additionally, should a survey route run along a railway, a railway vehicle may likewise be employed as survey vehicle.

[0028] During operation, when the survey vehicle is proximate/sufficiently close to the aerial cable, the generated acoustic signal can be picked up by the aerial cable through air and detected by DAS. The location of this acoustic signal along the aerial cable, i.e. the aerial cable length from this acoustic signal to DAS interrogator, is sufficiently close to the GPS location, i.e. geographic location, of the survey vehicle. If the survey

vehicle moves along the aerial cable route with constant acoustic signal excitation, the DAS can sense the acoustic signal location moving along the aerial cable as well. By matching the moving location of acoustic signal along the aerial cable and the moving GPS locations of the survey vehicle, the aerial cable route and length distribution can be geographically mapped.

[0029] Operationally, the overall procedure and implementation may proceed as follows:

1. Connect DAS interrogator to the aerial fiber optic cable.
2. Using DAS, continuously monitor the acoustic signal along the whole aerial fiber optic cable;
3. Find one frequency (or multiple frequencies) not constantly present in the DAS signal along the aerial fiber optic cable. Use this frequency as signature signal for acoustic excitation by the survey vehicle. Alternatively, a combination of multiple frequencies may be used as a signature signal.
4. Constantly generate the signature signal by operating the acoustic generator (e.g. speaker) on the survey vehicle while simultaneously logging a GPS location of the vehicle. Use DAS to constantly track the location of the signature signal along the aerial cable, by frequency filtering and pattern matching.
5. Drive/relocate the survey vehicle along the aerial cable route, sufficiently near the aerial cable route, so the aerial cable can be excited (picked up) by the acoustic signature signal propagating through air.
6. Match the moving signature signal location along the aerial cable and the GPS location of the survey vehicle in time domain for the aerial cabled route of interest.
7. Since the survey vehicle may not be able to move directly under or above the aerial cable, its GPS location may include distance error(s) relative to the actual geographic location of the aerial cable. To minimize this error, the GPS route of the aerial cable can be corrected by referring to the geographic route of the utility poles, since the aerial cable is supported by these poles and its route is limited and connected by these poles.
8. As a result, the aerial cable route and length distribution can be geographically mapped accurately.

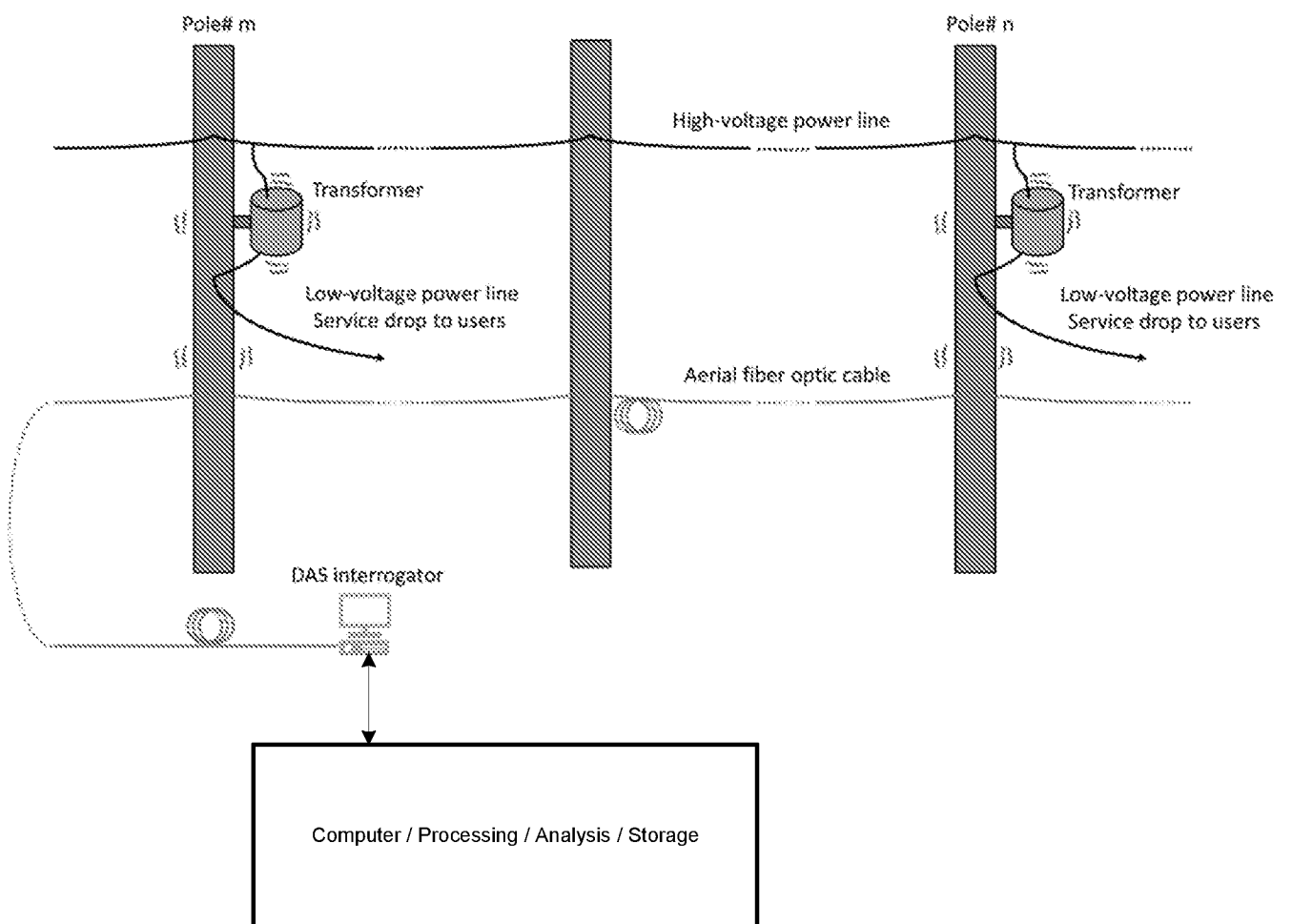
[0030] e can advantageously determine the geophysical locations - is then matching distributed fiber sensing generally describes systems and methods that include an interrogator system - conveniently and/or centrally located inside a station - which actively generates optical signals, introduces those signals into an optical fiber, and subsequently detects reflected (backscattered) signals that originate along the fiber. Operationally, such fiber acts as a passive link that passes or otherwise conveys environmental information back to the interrogator via the reflected signal(s). By processing the reflected/received signal(s), the interrogator derives information about the environmental conditions along the entire fiber.

[0031] While we have presented this disclosure using some specific examples, those skilled in the art will recognize that our teachings are not so limited. Accordingly, this disclosure should be only limited by the scope of the claims attached hereto.

Claims:

1. A method of localizing aerial fiber optical cable comprising:
 - using distributed acoustic sensing (DAS), monitor the aerial fiber optical cable;
 - apply a real time bandpass filter to returned DAS signals;
 - determine constant peaks exhibited in the returned, filtered DAS signals;
 - determine location(s) of electrical transformers situated on poles suspending the aerial fiber optical cable from the exhibited constant peaks.
2. The method of claim 1 further comprising:
 - determining length(s) of the aerial fiber optical cable between the poles.
3. The method of claim 1 wherein the determined location(s) of the electrical transformers is a geophysical location.
4. The method of claim 1 wherein the electrical transformers acoustically excite the fiber optical cable and the returned DAS signals are indicative of the acoustical excitation.
5. The method of claim 4 wherein the bandpass filter is one selected from the group consisting of 60Hz bandpass filter and 50Hz bandpass filter.
6. A method of localizing aerial fiber optical cable comprising:
 - using distributed acoustic sensing (DAS), monitor the aerial fiber optical cable;
 - apply a signature signal at different points along a length of aerial fiber optical cable while determining a GPS geolocation of that application;
 - associating the application of the signature signal at the different points with the determined GPS geolocation of the points;
 - geographically map an aerial fiber optical cable map route and length distribution from the associated signal(s) and geolocation of the points.

7. The method of claim 6 wherein the signature signal is determined by:
 - determining one or more frequencies not constantly present in the DAS signal along the aerial fiber optic cable; and
 - employing one or more of the determined frequencies as the signature signal.
8. The method of claim 7 wherein the signature signal is generated by an acoustic signal generator, said acoustic signal generator physically moved along the length of the aerial fiber optical cable.
9. The method of claim 8 wherein the acoustic signal generator is affixed to a survey vehicle selected from the group consisting of terrestrial vehicle, and aerial vehicle.
10. The method of claim 9 wherein the survey vehicle is one selected from the group consisting of manned survey vehicle and unmanned survey vehicle.

**FIG. 1**

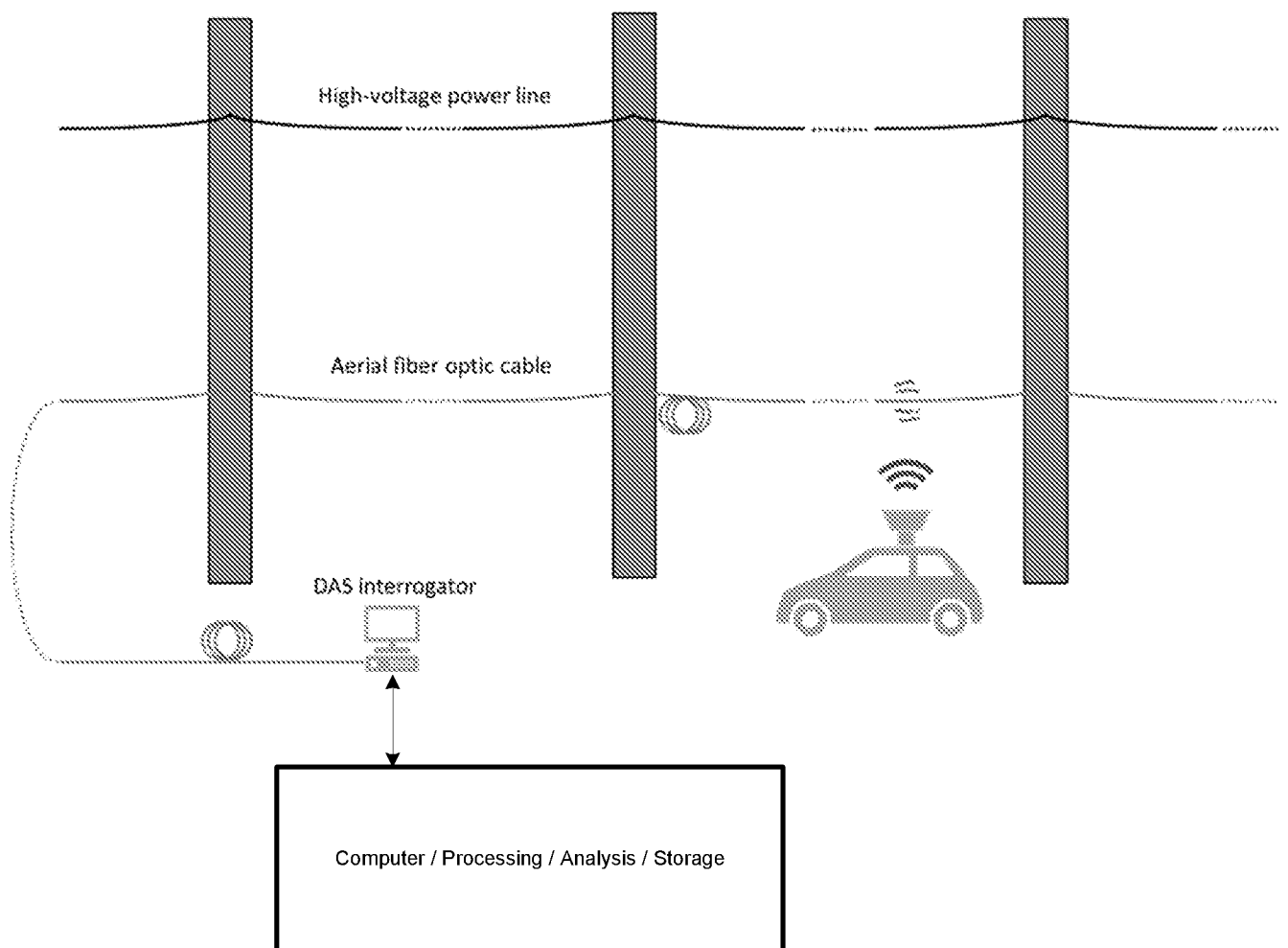
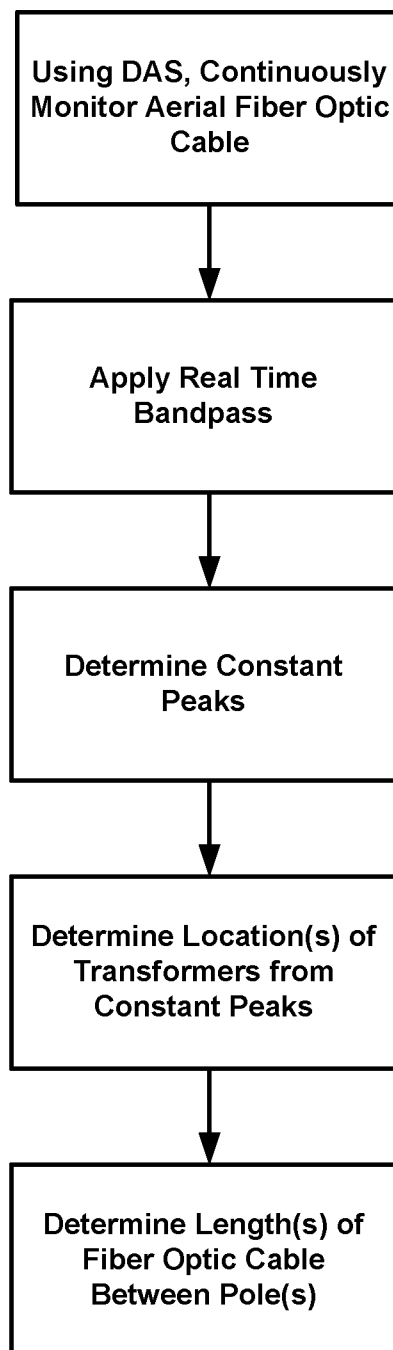
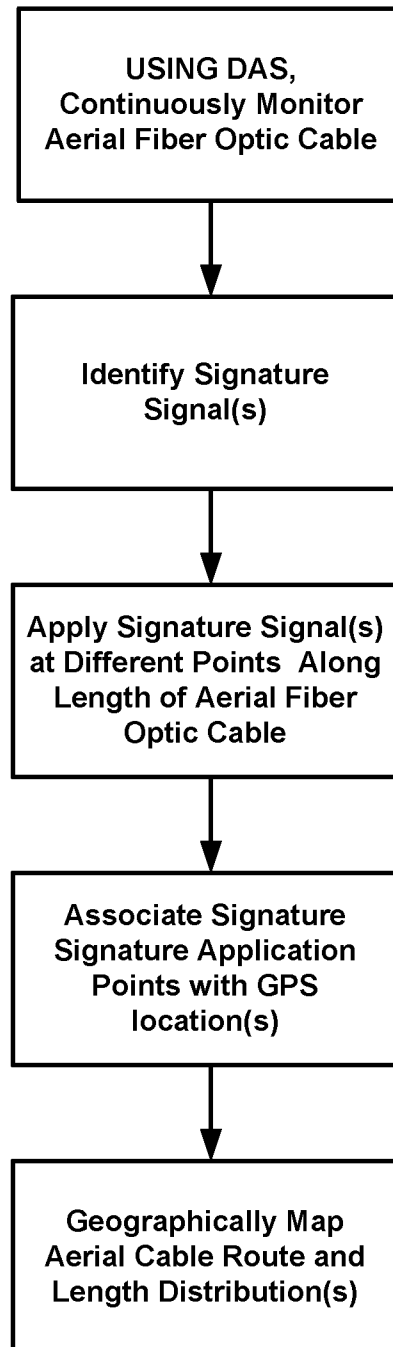


FIG. 2

***FIG. 3***

***FIG. 3***

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2020/026505**A. CLASSIFICATION OF SUBJECT MATTER****G02B 6/48(2006.01)i, H04B 10/2575(2013.01)i**

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)

G02B 6/48; F16B 2/08; G02B 6/46; G05B 11/01; G08B 21/00; H01B 7/00; H02G 1/02; H02G 7/18; H04B 10/2575

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: aerial fiber, location, sensing, DAS, peak

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	BANDWEAVER, Distributed Acoustic Sensing (DAS) technology employed to tackle overhead power line theft, case study of BNADWEAVER, 22 August 2018 [retrieved on 2020-07-09], Retrieved from <BANDWEAVER, https://www.bandweaver.com/wp-content/uploads/2018/08/Edesur-power-line-theft-prevention-case-study-v1.0.2.pdf > pages 1-3	1-10
Y	WO 2008-057810 A2 (CURRENT TECHNOLOGY, LLC) 15 May 2008 paragraphs [0080]-[0113]	1-10
A	JP 2012-228001 A (KANSAI ELECTRIC POWER CO INC. et al.) 15 November 2012 claims 1-3 and figure 3	1-10
A	JP 2002-107592 A (UCHIDA TANKO K.K.) 10 April 2002 paragraphs [0017]-[0018] and figure 3	1-10
A	JP 2002-281649 A (FURUKAWA ELECTRIC CO., LTD.) 27 September 2002 claims 1-2 and figures 2-3	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

29 July 2020 (29.07.2020)

Date of mailing of the international search report

29 July 2020 (29.07.2020)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2020/026505

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008-057810 A2	15/05/2008	US 2008-0106241 A1 US 2008-0106425 A1 US 2008-0106426 A1 US 2008-0109387 A1 US 2008-0122642 A1 US 2010-0156649 A1 US 7675427 B2 US 7701357 B2 US 7795877 B2 US 7804280 B2 US 7965193 B2 WO 2008-055084 A2 WO 2008-055084 A3 WO 2008-057807 A2 WO 2008-057807 A3 WO 2008-057808 A2 WO 2008-057808 A3 WO 2008-057809 A2 WO 2008-057809 A3 WO 2008-057810 A3	08/05/2008 08/05/2008 08/05/2008 08/05/2008 29/05/2008 24/06/2010 09/03/2010 20/04/2010 14/09/2010 28/09/2010 21/06/2011 08/05/2008 02/10/2008 15/05/2008 24/07/2008 15/05/2008 26/06/2008 15/05/2008 10/07/2008 10/07/2008
JP 2012-228001 A	15/11/2012	JP 5559092 B2	23/07/2014
JP 2002-107592 A	10/04/2002	None	
JP 2002-281649 A	27/09/2002	None	