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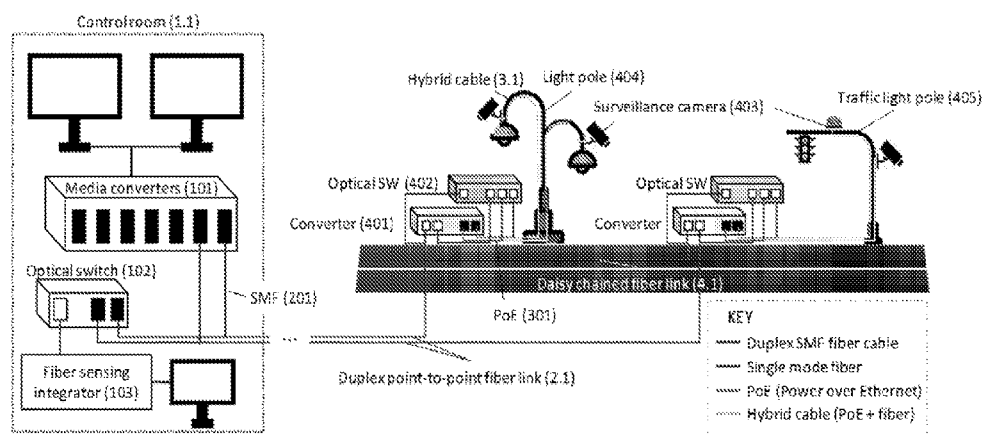
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(54) Title: DISTRIBUTED OPTICAL FIBER SENSING FOR SMART CITY APPLICATIONS

**FIG. 1**

(57) **Abstract:** Aspects of the present disclosure describe distributed optical fiber sensing for smart city applications in which distributed optical fiber sensing is integrated with a surveillance system into a single system such that the distributed sensing system may detect an event of interest and the surveillance system including cameras may be reoriented in response to verify and/or examine and/or acquire video of the event. Of particular advantage such distributed fiber sensing may include distributed acoustic sensing (DAS) for vibrational sensing and distributed temperature sensing (DTS) for temperature sensing. The integrated system employs shared optical fiber transport for the distributed sensing and the surveillance.



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DISTRIBUTED OPTICAL FIBER SENSING FOR SMART CITY APPLICATIONS

CROSS REFERENCE

[0001] This disclosure claims the benefit of United States Provisional Patent Application Serial No. 62/829,712 filed 04/05/2019 and United States Utility Patent Application Serial No. 16/839,686 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 surveillance systems, method, and structures. More particularly, it describes contemporary video surveillance systems advantageously enhanced by distributed optical fiber sensing systems, methods, and structures and smart city applications developed therefrom.

BACKGROUND

[0003] As is known in the surveillance arts, contemporary surveillance systems including cameras, controllers, and storage systems oftentimes employ optical fiber cable as a transmission media to provide for long distance transmission of surveillance video signals/data over long distance(s) at high bandwidth(s). Such optical fiber cable advantageously permits long distance(s) between the camera, controller, and storage elements while providing substantially little to no delay in transmission.

[0004] While optical fiber cable has proven quite useful for such applications, its primary function remains transmission of video signals between camera(s) and controller(s) and or storage systems.

SUMMARY

[0005] An advance in the art is made according to aspects of the present disclosure directed to systems, methods, and structures providing distributed fiber optic sensing over

optical fiber cable carrying surveillance video data thereby advantageously providing social sensing applications and the development of smart cities.

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 architecture of optical fiber sensing arrangement operating as part of a smart city environment according to aspects of the present disclosure;

[0008] **FIG. 2(A)** and **FIG. 2(B)** are schematic diagrams of illustrative new cable(s) that may be employed in the architecture of **FIG. 1** according to aspects of the present disclosure; and

[0009] **FIG. 3** is a schematic diagram of the illustrative architecture of **FIG. 1** as part of an educational/school application according to aspects of the present disclosure.

[0010] 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

[0011] 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.

[0012] 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.

[0013] 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.

[0014] 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.

[0015] Unless otherwise explicitly specified herein, the FIGs comprising the drawing are not drawn to scale.

[0016] **FIG. 1** shows a schematic diagram of an illustrative architecture of optical fiber sensing arrangement operating as part of a smart city environment according to aspects of the present disclosure. Those skilled in the art will recognize that this architecture includes aspects of current optical fiber-based surveillance system designs that include a point-to-point fiber link optically connecting a media converter **101** shown as located inside a control room **1.1** to a remote media converter **401** located in field. We note that – according to aspects of the present disclosure – the fiber link may advantageously provide distributed optical fiber sensor functionality in addition to conventional video communications noted previously.

[0017] When so configured, the optical fiber operates as a distributed optical fiber sensor providing social sensing data and resulting information along entire fiber infrastructure. As schematically illustrated in the figure, such infrastructure according to

the present disclosure may include one or more optical switch **102**, interrogator/integrator **103** which are shown as being positioned in a common control room **1.1**.

[0018] While not explicit in **FIG. 1**, we note two key elements in this inventive architecture are SMF fiber cables **2.1** for point-to-point and daisy chained fiber link **4.1** and Hybrid cables **3.1** which are employed instead of a single fiber link and/or PoE (power over Ethernet) cables frequently used in current arrangements.

[0019] **FIG. 2(A)** and **FIG. 2(B)** are schematic diagrams of illustrative new cable(s) that may be employed in the architecture of **FIG. 1** according to aspects of the present disclosure.

[0020] As shown in **FIG. 2(A)** figure, a duplex single mode fiber (SMF) fiber cable **2.1** includes two single mode fiber(s) (SMF **201**, **202**) - one used for video transmission from surveillance camera, the other one used for distributed fiber sensing.

[0021] Those skilled in the art will know and appreciate that typically, unshielded twisted pair, power-over-Ethernet type (PoE) cable are now widely used in the field to connect devices such as converters **401** and surveillance cameras **403**, which provide video transmission bandwidth and electrical power to the cameras. In our inventive architecture, the hybrid cable **3.1** depicted in **FIG. 2(B)** - which includes one PoE **301** cable and one SMF **201** - is employed instead of the traditional PoE cable. As a result, video transmission, electrical power to the camera, and social sensing applications via distributed fiber sensing operation are all advantageously provided.

[0022] With continued and simultaneous reference to **FIG. 1**, **FIG. 2(A)**, and **FIG. 2(B)**, during operation, a sensing interrogation signal (pulse) is generated by fiber sensing integrator **103**. The generated signal is directed through optical switch **102**, duplex point-to-point fiber link **2.1**, field optical switch **SW 402**, single mode fiber (SMF **201**) positioned inside hybrid cable **3.1**, light pole **404** and finally to surveillance camera **403**.

[0023] Since, according to aspects of the present disclosure, the entire fiber length in the architecture operationally performs as sensing media which can advantageously be used for social sensing – or other - applications.

[0024] By way of an illustrative example, if light poles **404** - onto which are mounted surveillance cameras **403** - are located in a parking lot, car horns and car security alarms can be advantageously detected by distributed vibration sensing and acoustic sensing techniques for parking lot security applications. When the light poles **404** or traffic light poles **405** – onto which are mounted the surveillance cameras - are located instead on/near public roads, car crash events and other acoustic/vibratory events may likewise be detected by distributed optical fiber sensing technologies.

[0025] Still further, conditions of poles (such as light poles, traffic light poles, utility poles, etc., onto which surveillance cameras are mounted) may also be detected by distributed optical fiber sensing for pole health monitoring applications.

[0026] Finally, yet another variation to our architecture uses a daisy chained fiber link **4.1** to connect two converters in the field. As will be appreciated by those skilled in the art, such converters operate to convert electrical or other output signals from the cameras to optical signals for conveyance over the optical fiber. When so configured, a road surface temperature may be determined by distributed temperature sensing to track pavement condition(s). Advantageously, such operation permits the determination of an actual pavement temperature instead of estimating such temperatures – thereby permitting better estimates of road surface temperatures and resulting pavement distress that results.

[0027] **FIG. 3** is a schematic diagram of the illustrative architecture of **FIG. 1** as part of an educational/school application according to aspects of the present disclosure. With reference now to that figure, one may observe yet another application of our inventive disclosure wherein distributed optical fiber sensing and surveillance video share optical fiber links.

[0028] In an arrangement like that of **FIG. 2**, an entire control and monitoring operation including control and monitoring systems are shown located in a control room **1.1** which can be – for example - a police station or a monitoring office up to 20-km away from a school. Instead of PoE cables, hybrid cables (3.1) is employed for video transmission and sensing applications.

[0029] Advantageously, the duplex point-to-point fiber link **2.1** can be located on walls, floors, ceilings, and can be used for person/intruder detection, temperature and structure monitoring, or safety/security considerations such as detecting unlawful violent events including shootings and/or bombings. Additionally, since our optical fiber sensing technology is integrated with surveillance systems, conveying triggered alarms to monitoring screens in real-time response to events is advantageously realized. In this illustrative example, the cameras can be controlled – or automatically zoom in to the targeted subjects and confirm events in real time. One illustrative summary of applications is listed in Table 1.

Sensing technology	Locations & Applications		
	Public roads in cities	Parking lot security	Schools
Distributed acoustic sensing (DAS)	• Car crash • People screaming • Traffic light pole health • Help surveillance cameras to locate events	• Car horns • Car security alarm • People screaming • Light pole health • Help surveillance cameras to locate events	• Gun shoot • People screaming • Structure health • Help surveillance cameras to locate events
Distributed temperature sensing (DTS)	• Road surface temperature		• Building temperature

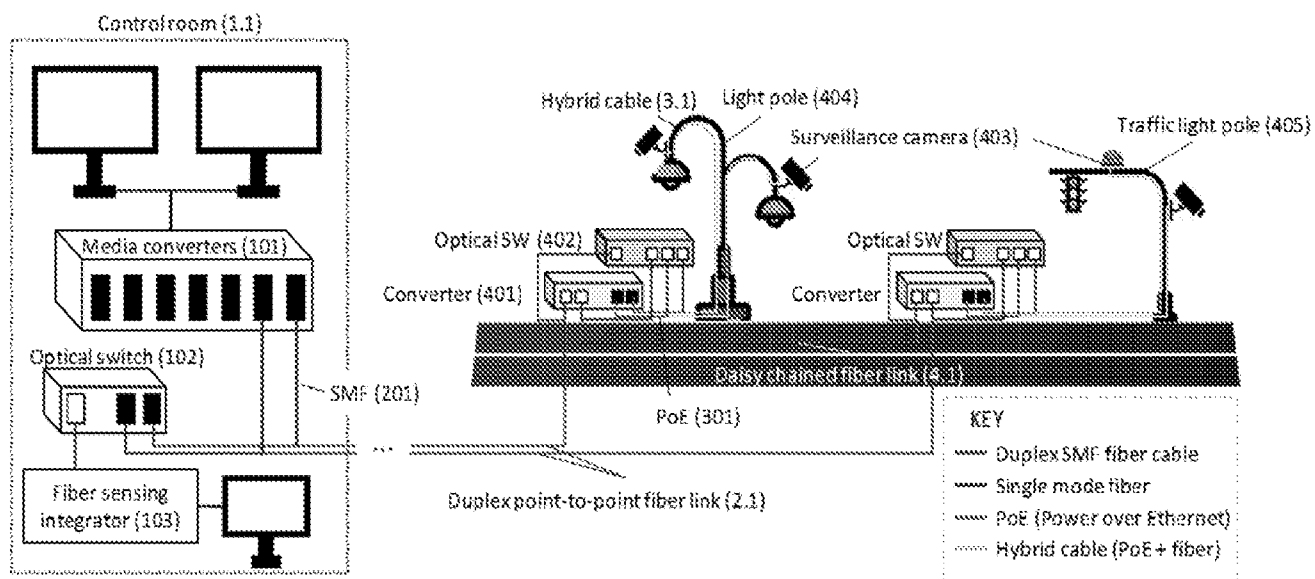
Table 1

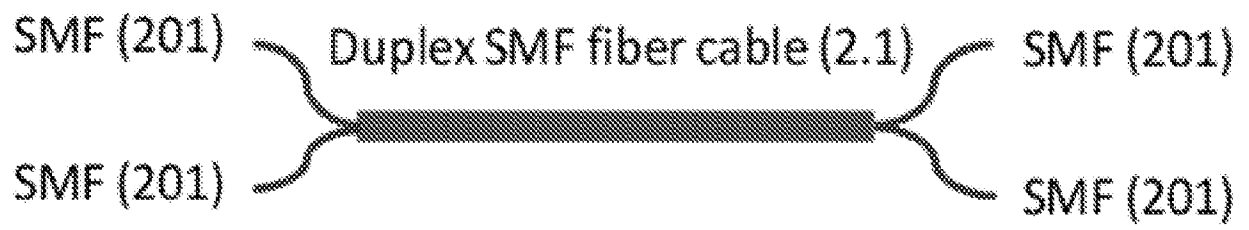
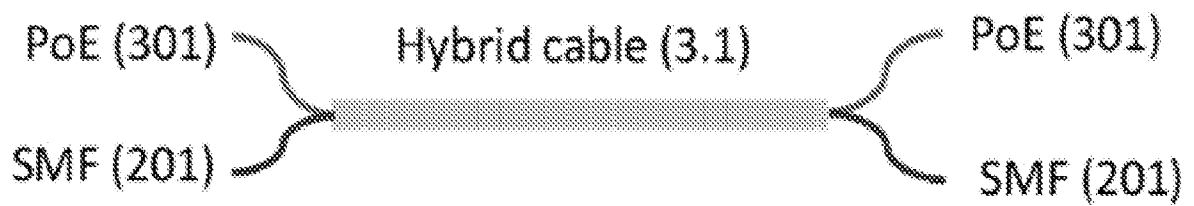
[0030] While we have presented this disclosure using some specific examples, those skilled in the art will recognize that our teachings are not so limited. Accordingly, this disclosure should be only limited by the scope of the claims attached hereto.

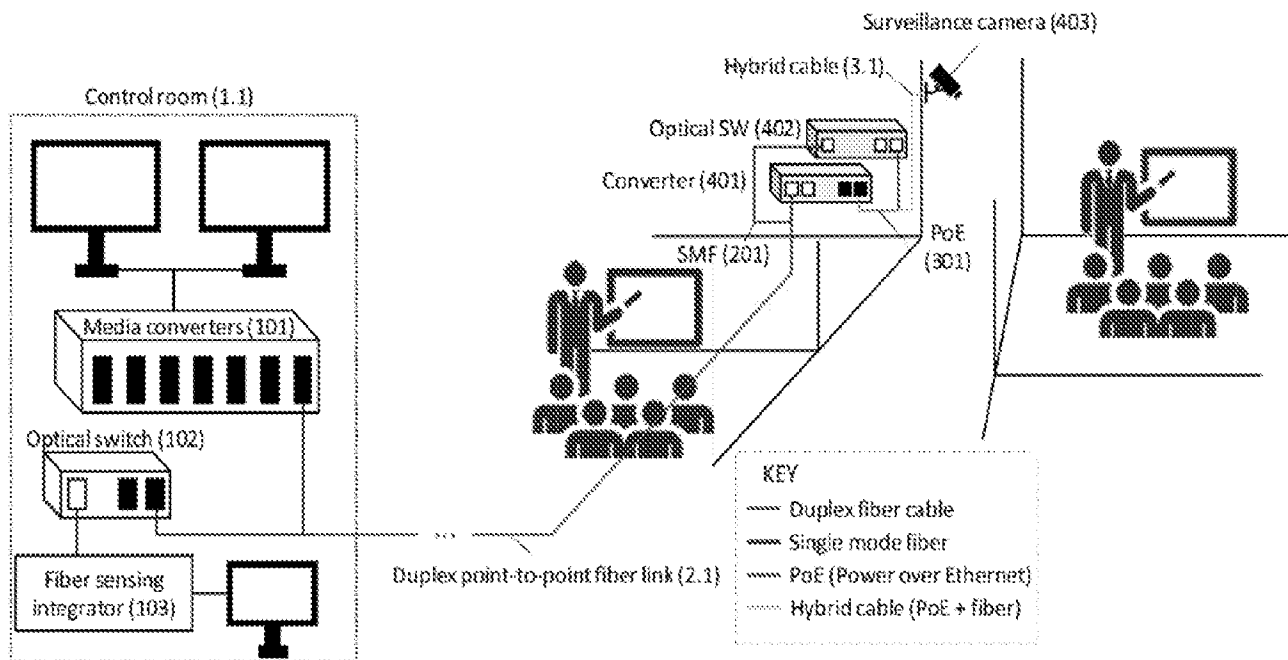
Claims:

1. An integrated distributed optical fiber sensing and video surveillance system comprising:
 - a length of optical fiber;
 - a distributed optical fiber sensing interrogator in optical communication with the length of optical fiber; and
 - a video surveillance system in optical communication with the length of optical fiber, the video surveillance system including one or more media converters and one or more surveillance cameras in communication with the one or more converters.
2. The integrated system of claim 1 further comprising:
 - one or more optical switches in optical communication with the length of optical fiber.
3. The integrated system of claim 2 wherein at least one of the one or more surveillance cameras are in communication with a length of hybrid cable, said hybrid cable including a power-over-Ethernet (PoE) type cable and a single mode optical fiber (SMF) cable, said hybrid cable connecting the at least one surveillance camera to an optical switch and a media converter via the SMF and PoE cables, respectively.
4. The integrated system of claim 3 wherein the length of optical fiber comprises a length of duplex single mode fiber (SMF) cable, said duplex SMF cable including two, individual single mode optical fibers.
5. A method of operating an integrated distributed optical fiber sensing and video surveillance system, said system comprising:
 - a length of optical fiber;
 - a distributed optical fiber sensing interrogator in optical communication with the length of optical fiber; and

- a video surveillance system in optical communication with the length of optical fiber;
- said method comprising:
- simultaneously operating the distributed optical fiber sensing interrogator and the video surveillance system;
 - detecting an event of interest via the distributed optical fiber sensing; and
 - configuring the video surveillance system in response to the detected event.
6. The method of claim 5 wherein the video surveillance system includes one or more video surveillance cameras and the configuring of the video surveillance system in response to the detected event includes reorienting one or more of the video surveillance cameras.
7. The method of claim 6 wherein the distributed optical fiber sensing comprises sensing one or more characteristics selected from the group consisting of temperature (distributed temperature sensing – DTS) and mechanical vibrations (distributed acoustic sensing – DAS).
8. The method of claim 7 wherein the distributed optical fiber sensing senses infrastructure elements including one selected from the group consisting of buildings, roadways, and utility structures.
9. The method of claim 5 further comprising sending an alarm in response to the detected event.
10. The method of claim 9 wherein the interrogator generates optical pulses, introduces them into the optical fiber and receives reflected signals from the fiber, directs analysis of the reflected signals to determine sensing events.

**FIG. 1**

***FIG. 2(A)******FIG. 2(B)***

**FIG. 3**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2020/026760**A. CLASSIFICATION OF SUBJECT MATTER****H04N 7/18(2006.01)i, H04N 7/22(2006.01)i, H04B 10/25(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)

H04N 7/18; B29C 70/70; G01D 5/26; G08B 13/196; H04B 10/80; H04N 21/443; H04N 5/84; H04N 5/85; H04N 7/22; H04B 10/25

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: optical fiber, sensor, surveillance, hybrid

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2012-0176496 A1 (LEE A. CARBONELL et al.) 12 July 2012 paragraphs [0020]–[0022], [0029]–[0032]; claims 1, 11; and figure 2	1–10
Y	US 2018-0219635 A1 (RADIUS UNIVERSAL LLC) 02 August 2018 paragraphs [0040]–[0041], [0160], [0223]; claim 1; and figures 1A, 14A, 25	1–10
A	US 2016-0171853 A1 (COMCAST CABLE COMMUNICATIONS, LLC) 16 June 2016 claims 1–2	1–10
A	WO 2018-227281 A1 (ADVANCED OPTO-MECHANICAL SYSTEMS AND TECHNOLOGIES INC.) 20 December 2018 claim 1	1–10
A	KR 10-1664313 B1 (FIBER&NETWORKING CO., LTD.) 10 October 2016 paragraphs [0034]–[0039]; and figure 2	1–10



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2020/026760

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