

TITLE OF THE INVENTION:

INTELLIGENT FIBER ROPE TERMINATION, MODULE, AND NETWORKING
TECHNOLOGIES

CROSS-REFERENCES TO RELATED APPLICATIONS

This non-provisional patent application is a continuation-in-part of U.S. Patent Application Serial Number 15/445,306 and claims the benefit, pursuant to 37 C.F.R. section 1.53(c), of an earlier-filed provisional patent application assigned serial number 62/686,210. The parent application listed the same inventors and remains pending as of the time of this filing.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR
DEVELOPMENT

Not Applicable.

MICROFICHE APPENDIX

Not Applicable member

DESCRIPTION

Title of the Invention: Intelligent Fiber Rope Termination, Module, and Networking Technologies

1. Technical Field.

5 This invention relates to the field of tensile strength members. More specifically, the invention comprises an intelligent cable module that can be placed in any desired position along a rope or cable. The module preferably includes an instrument package useful for things such as position monitoring and load monitoring, as well as other components that are connected to the instrument package.

10 2. Background Art.

In this disclosure the terms “rope” and “cable” are used interchangeably. Both are examples of a “tensile strength member,” meaning a component that readily transmits tensile forces but not compressive forces. Tensile strength members must generally be connected to other components in order to be useful. A flexible cable provides a good example. Most
15 cables include some type of end-fitting configured to transmit a load. For example, a cable used in a hoist generally includes a lifting hook on its free end. This lifting hook may be rigged to a load. The assembly of an end-fitting and the portion of the cable to which it is attached is commonly called a “termination.” A termination is a useful point for the addition of the inventive intelligent cable module, though such a module can be added at other points
20 as well.

The present invention has application to many fields where cables are used. A non-exhaustive listing of applicable fields includes offshore lifting, ship mooring, drag line cranes (in both fixed and moveable rigging), power shovels (in both fixed and moveable rigging), civil structure tendons (suspension bridges and the like), and floating structure moorings
25 (such as offshore oil rigs)

Most high-strength cables are presently made of steel. The cable is a wound or braided assembly of individual steel wire. An end fitting (such as a lifting hook) is often attached to the steel cable by placing a length of the cable within a cavity running through a portion of the end fitting. The wires within the end fitting are splayed apart and a potting
30 compound is then used to lock the wires within the fitting. The term “potting compound” means any substance which transitions from a liquid to a solid over time. Examples include molten lead, thermoplastics, and UV-cure or thermoset resins (such as two-part polyesters or

epoxies). Other examples include plasters, ceramics, and cements. The term “solid” is by no means limited to an ordered crystalline structure such as found in most metals. In the context
35 of this invention, the term “solid” means a state in which the material does not flow significantly under the influence of gravity. Thus, a soft but stable wax is yet another example of such a solid.

Molten lead was traditionally used as a potting compound for steel cables. Once the individual wires were splayed within the expanding cavity of an end-fitting, molten lead was
40 poured into the cavity. The lead then solidified and locked a portion of the cable in the cavity. In more recent years lead has been replaced by high-strength epoxies.

Modern cables may still be made of steel, but high-strength synthetic filaments are becoming more common. These include DYNEEMA (ultra-high-molecular weight polyethylene), SPECTRA (ultra-high-molecular weight polyethylene), TECHNORA
45 (processed terephthaloyl chloride), TWARON (para-aramid), KEVLAR (para-aramid), VECTRAN (liquid crystal polymer), PBO (polybenzobisoxazole), carbon fiber, and glass fiber (among many others). Modern cables may also be made of older, lower-strength synthetic materials such as NYLON. In the case of high-strength synthetics, the individual filaments have a thickness that is less than that of human hair. The filaments are very strong
50 in tension, but they are not very rigid. They also tend to have low surface friction. These facts make such synthetic filaments difficult to handle during the process of adding a termination and difficult to organize. Hybrid cable designs are also emerging in which traditional materials are combined with high-strength synthetic materials. These present additional challenges, since the metal portions may be quite stiff while the synthetic portions
55 will not be.

Those skilled in the art will know that cables made from synthetic filaments have a wide variety of constructions. In many cases a protective jacket will be provided over the exterior of the synthetic filament. This jacket does not carry any significant tensile load and it may therefore be made of a different material.

60 Most larger cables are made as an organized grouping of smaller cables. The smaller cables are often referred to as “strands.” One example is a parallel core of synthetic filaments surrounded by a jacket of braided filaments. In other cases the cable may be braided throughout. In still other examples the cable construction may be: (1) an entirely parallel construction enclosed in a jacket made of different material, (2) a helical “twist” construction,

65 (3) a more complex construction of multiple helices, multiple braids, or some combination of helices and braids, or (4) a hybrid construction including metallic constituents.

The reader is referred to commonly-owned U.S. Patent No. 8,371,015 for more detailed descriptions regarding the application of an attachment to a sub-component of a larger cable. The '015 Patent explains how individual anchors can be attached to the strands
70 and the anchors can then be attached to a common collector to create a uniform load-bearing structure.

The present invention is not limited to multi-stranded terminations. Any form of cable termination may be used, such as a single socket for example. The exemplary embodiments depicted all include multi-stranded terminations but this fact should not be
75 viewed as limiting. The embodiments specifically described pertain primarily to the field of deep water lifting and lowering. The invention is by no means limited to this field, however.

Modern high-performance cables incorporating synthetic fibers (in pure form or in hybrid form) provide the same strength as steel cables but with a substantial weight reduction. For long hoisting operations the weight of the cable often exceeds the weight of
80 the payload. A reduction in the weight of the cable results in a direct increase in payload. The inventive products described herein will most often be applied to high-strength cables (5 Tons to 2000 Tons or even more). These applications are often critical in nature. Thus, it is useful to incorporate intelligent cable modules that can monitor a cable's condition while it remains in operation. The present invention provides such a capability.

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SUMMARY OF INVENTION

The present invention comprises a cable including an integrated intelligent cable module. The module preferably includes an integral instrument package. The instrument package may assume many forms and may serve many purposes. In a preferred embodiment,
90 the module includes a position-determining system and an on-board processor. The processor determines a current location in space for the module based on the information it is receiving. This positional information may then be transmitted to an external receiver. In the scenario where the module is attached to a termination near a payload, the positional information may be used by an external positioning device (such as a crane) to control the
95 motion of the cable

The module also preferably includes load-monitoring and recording features. These features act as a “black box” for the cable, monitoring its performance and reporting (in real-time or at a later time) any exceedances or any deterioration in performance or structural integrity.

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BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an exploded perspective view, showing an exemplary intelligent anchor made according to the present invention.

105 FIG. 2 is a sectional elevation view, showing one type of strand termination that may be used.

FIG. 3 is a sectional elevation view, showing representative instrumentation that may be added to a strand termination.

110 FIG. 4 is a sectional view, showing one possible construction for a multi-stranded cable.

FIG. 5 is a plan view, showing a collector.

FIG. 6 is an exploded perspective view, showing additional features of the housing and collector.

115 FIG. 7 is a sectional elevation view, showing a version in which a separate collector and housing is used.

FIG. 8 is a sectional elevation view, showing a completed assembly using the components of FIG. 7.

FIG. 9 is a schematic view, showing a representative instrumentation package for an inventive termination.

120 FIG. 10 is a sectional elevation view, showing another embodiment of the inventive termination.

FIG. 11 is a perspective view, showing an inventive termination with thrusters.

FIG. 12 is a sectional elevation view, showing a strand termination with an embedded sensing/comm element.

125 FIG. 13 is a perspective view, showing the use of the inventive termination to place a payload in the deep water lifting environment.

FIG. 14 is a perspective view, showing the addition of an external camera to the assembly of FIG. 13.

FIG. 15 is a perspective view, showing the addition of a pair of ROV garages and
130 ROV's to the intelligent cable termination.

FIG. 16 is a perspective view, showing one of the ROV's of FIG. 15 in operation.

FIG. 17 is a perspective view, showing a different payload configuration.

FIG. 18 is an elevation view, showing a common construction for a braided cable.

FIG. 19 is a perspective view, showing how the strands of a cable can be loosened to
135 expose a central void and gaps between the individual strands.

FIG. 20 is a perspective view, showing an exemplary intelligent cable module configured to fit in the central void of a braided cable.

FIG. 21 is an elevation view with a cutaway, showing the intelligent cable module of
FIG. 20 installed inside a cable.

FIG. 22 is a sectional elevation view, showing the use of clamping collars to hold the
140 module of FIG. 21 in position.

FIG. 23 is a perspective view, showing an embodiment of the intelligent cable module including radial prongs to stabilize its position.

FIG. 24 is an elevation view, showing an embodiment of an intelligent cable module
145 configured to clamp to the exterior of a cable.

FIG. 25 is an elevation view, showing the use of multiple intelligent cable modules along a cable in a marine lifting application.

FIG. 26 is a perspective view showing how an intelligent cable module can be added at any desired position along a cable's length.

FIG. 27 is an exploded perspective view, showing the addition of an intelligent cable
150 module in a length of cable.

FIG. 28 is an elevation view, showing the addition of two intelligent cable modules in a length of cable.

FIG. 29 is a schematic view, showing a master-based network among intelligent cable
155 modules and other systems.

FIG. 30 is a schematic view, showing a masterless network among intelligent cable modules and other systems.

FIG. 31 is a perspective view, showing an intelligent cable module integrated into a ship mooring system.

160 FIG. 32 is a plan view, showing the system of FIG. 31

FIG. 33 is a perspective view, showing the incorporation of an intelligent cable module in a small single-strand termination.

FIG. 34 is a sectional elevation view, showing internal details of the embodiment of FIG. 33.

165 FIG. 35 is an elevation view, showing an exemplary graphical user interface.

REFERENCE NUMERALS IN THE DRAWINGS

	10	cable
	12	strand
170	18	anchor
	20	cavity
	22	potted region
	24	loading stud
	26	male thread
175	28	threaded engagement
	30	strand termination
	34	collector
	38	receiver
	40	nut
180	44	hemi bearing
	46	opening
	48	through hole
	50	central opening
	64	middle strand collector
185	66	distal strand collector
	68	load cell
	70	jacket
	72	core
	74	housing

190	76	clevis structure
	78	transverse hole
	80	bolt
	82	receiver
	84	recess
195	86	cavity
	88	first instrument package
	90	second instrument package
	92	connection
	94	core termination
200	96	battery
	98	power supply
	100	inertial measurement system
	102	processor
	104	memory
205	106	external power connector
	108	external data connector
	110	acoustic antenna
	112	acoustic transducer
	114	I/O port
210	116	I/O port
	118	I/O port
	120	load cell
	122	load cell
	124	load cell
215	126	I/O port
	128	pressure sensor
	130	temperature sensor
	132	intelligent cable termination
	134	thruster controller
220	136	salinity
	138	extended housing

	140	thruster
	142	trunnion mount
	144	sensing/comm element
225	146	sensor
	148	sensor lead
	150	sensor lead
	160	potting surface
	162	payload
230	164	lifting tang
	166	connector
	168	cable
	170	camera
	172	ROV garage
235	174	ROV
	176	ROV garage
	178	ROV
	180	tether
	182	connector
240	184	cable
	186	connector
	188	tang
	190	sling
	192	release mechanism
245	194	pallet
	196	leg
	198	central void
	200	inter-strand void
	202	intelligent cable module
250	204	communication strand
	206	connector
	208	module casing
	210	bulging portion

	212	clamping collar
255	214	radial prong
	216	casing half
	218	casing half
	220	antenna
	222	external display
260	224	vessel
	226	through hole
	228	nut
	230	master node
	232	node
265	234	controlling computer
	240	vessel
	242	bollard
	244	mooring line
	246	sling
270	248	transition
	250	mooring stay
	252	quay
	254	winch
	256	controller
275	258	termination
	260	anchor
	262	loading flange
	264	antenna
	266	strain gauge
280	268	connection
	270	monitor
	272	windows display
	274	line identification data
	276	monitoring parameters
285	278	potting transition

280 filament limit

DESCRIPTION OF EMBODIMENTS

FIG. 1 provides an exploded view of an exemplary intelligent cable module that is configured to be located near one end of a cable. The intelligent cable module is therefore referred to as an “intelligent cable termination.” Intelligent cable termination 132 is shown as an exploded assembly in FIG. 1. The particular cable 10 shown has nine individual strands 12 surrounding a core. All these components are encompassed within a surrounding jacket. A portion of the jacket is removed to reveal the individual strands and the core. A strand termination 30 is affixed to the end of each individual strand 12. Each strand termination 30 is then attached to collector 34.

The intelligent cable termination 132 is configured to attach to an external element (such as a payload to be hoisted and placed by a crane). A connecting feature can be added to collector 34. However, in the version shown, the connecting feature (clevis structure 76) is incorporated as part of a separate housing 74. Housing 74 connects to collector 34. Using this approach, tension carried by strands 12 is transmitted to the collector, then to housing 74 and finally through clevis structure 76 to an external element.

In addition to carrying the cable's load, housing 74 in this embodiment provides additional internal space for housing an instrument package or packages. The instrument package or packages allows the integrated termination to become an “intelligent” termination, as will be described subsequently.

Middle strand collector 64 slides over the splayed strands and attaches to the perimeter of collector 34. Distal strand collector 66 (which is split into two halves in this version), clamps over the small end of the middle strand collector and seals the interface between the middle strand collector and the jacketed portion of the cable. These components direct the transition of the strands from their configuration within the cable to the “splayed” state proximate collector 34.

FIG. 2 is a sectional elevation view showing an exemplary structure for a strand termination 30. The individual filaments within strand 12 (which may be a million filaments or more in the case of an advanced synthetic material) are connected to anchor 18, such as by potting a length of the filaments within cavity 20 to form potted region 22. Loading stud 28 is connected to anchor 18 via threaded engagement 28. The loading stud is equipped with a

suitable force-transferring feature – in this case male thread 26. This assembly thereby transmits tensile loads from strand 12 to loading stud 24.

320 FIG. 3 is a sectional elevation view depicting an exemplary connection between strand termination 30 and collector 34. In this version a ball-and-socket connection is used. Opening 46 passes through collector 34 at an angle. A hemispherical receiver 38 is provided in the portion of the opening opposite the strand. Hemi bearing 44 rests in receiver 38. Loading stud 24 passes through hemi bearing 44. Load cell 68 is placed on top of hemi
325 bearing 44. Nut 40 secures the assembly in place. Each individual strand termination includes its own adjusting nut. The nuts may be used to individually allocate the total tension among the strands. Load cell 68 provides an electrical output that corresponds to the amount of compressive load it is presently experiencing. Each individual strand termination is preferably provided with a load cell so that the load on each strand can be monitored. In this
330 example the intelligent cable module receives and monitors the information from the load cells. It can also place this information in a suitable communication format and transmit it to an external monitoring system.

 The load cell shown in this version is illustrative of any load/stress/strain sensing device that is incorporated into a cable or strand's load path. Other types of devices may be
335 substituted. As an additional example, a pressure sensing device can be provided within the potted region inside the anchor. As still another example, a strain gauge may be attached to the exterior surface of the strand termination.

 FIG. 4 shows a cross sectional view through an exemplary cable assembly of the type depicted in FIG. 1. This particular cable has ten sub-groupings – core 72 surrounded by nine
340 strands 12. Optional jacket 70 may be provided to surround and protect the other components. While cable jackets are not common in the field of deep water lowering and lifting (primarily due to inspection limitations), with the addition of sensory technologies, an external jacket may be an advantageous feature. External jackets are more common in other applications.

345 FIG. 5 depicts a plan view of collector 34 (the same version as shown in FIG. 1). Center opening 50 receives core 72. Nine openings 46 are provided for the nine strands 12. Nine through holes 48 are provided for bolts that are used to attach the collector to the housing.

FIG. 6 provides a perspective view of collector 34 and housing 74. The reader will
350 note how the nine through holes 48 in the collector align with nine receivers 82 in housing
74. Each receiver 82 includes a female thread. Nine bolts 80 are passed through the receiver
and into the nine threaded receivers 82 in the housing. The bolts are then tightened to secure
the collector to housing 74.

In this example housing 74 is machined as one integral piece. It includes clevis
355 structure 76 with transverse hole 78. This is configured to receive a tang and cross-pin in
order to attach the housing to some external element. An example of an external element
would be a payload that is to be lifted and moved using the inventive cable termination. In
many cases additional rigging (such as lifting slings) and hardware will be added to the clevis
structure shown. Thus, the clevis structure should be viewed as exemplary and non-limiting.

360 Housing 74 includes an internal recess 84 that may be used to house one or more
instrumentation packages. FIG. 7 shows a sectional elevation view through collector 34 and
housing 74. Cavity 86 is provided in the portion of the housing that faces the collector. One
or more additional recesses may be provided where the limitations of structural strength
requirements permit. In the example shown, two such recesses 84 are provided.

365 It is preferable to provide space for instrumentation within the integrated termination
itself. However, any available region around the integrated termination could be employed as
space for instrumentation – provided that it is sufficiently protected (for applications needing
such protection). The protective body for the instrumentation need not be the same body
that is used for the integrated termination. Housing 74 is preferably quite robust, and in some
370 cases may be sealed from water and/or water pressure. Given that most instruments are
sensitive to water and / or the pressures of deep water operation, a boundary will typically
need to be established for ocean lifting applications. This can either be done within housing
74 as an example, or individually between instrument package components. For example the
power source and sensors may have independently sealed packages for this purpose. Housing
375 74 would then not require an overall seal.

The user will note in FIG. 7 how bolts 80 may be placed in through holes 48 and
threaded into receivers 82. FIG. 8 shows a sectional view through an assembly made
according to the present invention (The section is taken on the same plane used for FIG. 7).
Core termination 94 is provided on the end of core 72 in this example. It is secured within
380 central opening 50 in collector 34. In this version core 72 is not intended to carry significant

tension. It houses communication and / or power lines that extend along the entire length, or in some cases a portion, of the cable.

First instrument package 88 and second instrument package 90 are contained within housing 74. These instrument packages are connected to the elements in core 72 (such as fiber optic lines and electrical conductors). The instrument packages are also connected (in this version) to the load cells monitoring the load on each individual strand. As will be known to those working in the field of deep water lifting, the addition of power, communication, data, air, fluid, or any form of auxiliary service line can be incorporated within the strength member to increase the service context of the intelligent cable module. These service lines can be incorporated in countless configurations, such as inside strands, between strands, within layers of the jacket, temporarily wrapped and unwrapped around the outside of the cable, etc. The proposed invention is not limited to any specific cable design. However, the addition of auxiliary service lines can significantly increase the advantages of the inventive termination.

As an example of the above, the addition of fiber optics and in some cases power within the lifting cable may allow high speed data transfer for real-time feedback of position, or operation of subsea ROVs and/or AUVs. In such cases, the intelligent termination can more easily become the power and/or communication hub for additional machines and/or devices operating at depth.

The reader will also note in the example of FIG. 8 that middle strand collector 64 has been attached to the outer perimeter of collector 34. The unification of these elements (see FIG. 1 - housing, collector, middle strand collector, distal strand collector, and cable) creates a solid and protective assembly. As shown in FIG. 8, the instrument packages and associated connections are well-protected inside a very solid surrounding structure. This configuration is preferable, as a cable termination frequently lives in a hostile environment. As covered previously, this housing may take on many shapes and forms, including separate or attached housings that may not be within the termination casing.

The instrument package(s) may include many types of electronic devices. FIG. 9 schematically depicts an exemplary embodiment to aid the reader's understanding. The reader should first bear in mind that some versions will include external power and/or communication connections, while others will not. The unconnected versions will run on internal power and may save information for subsequent downloading, or pulse information

to other sources on an interval or as-needed basis (such as a strand integrity breach alarm signaling an acoustic transmitter to communicate to a ship-board receiver). The connected
415 versions may transfer information up the cable (to a receiver on board a surface vessel) as they are being used. FIG. 9 shows an externally-connected version (meaning a version that is designed to maintain communication up the cable).

The instrument package(s) may include only analog devices. An example would be load cell circuitry that sends a sensed value up the cable. It is preferable in most cases,
420 however, to include digital devices such as one or more processors. These may be used to convert information to a digital format and thereby facilitate easier retention and transmittal. The example of FIG. 9 uses digital circuitry.

Processor 102 is ideally a programmable device capable of running suitable software. It includes an associated memory 104. The memory is preferably non-volatile so that it may
425 store data over time even if the power is lost. Power supply 98 provides stable power to all the components shown (The power connections are not depicted). The power supply may draw input power from battery 96, from external power connector 106, or both. Additionally it may draw power from an alternate source such as an ROV tether or auxiliary power source on the sea floor.

430 Inertial measurement system 100 ("IMS") provides position and orientation data to the processor. It preferably provides full six degree of freedom information. Using conventional nomenclature, this means that the IMS provides such information as X-axis position, Y-axis position, Z-axis position, roll angle, pitch angle, and yaw angle. The IMS may also provide such information as a rate-of-change for these values. The information
435 provided by the IMS allows the processor to "know" the intelligent module's position in space and its orientation. This assumes, of course, that accurate initial information is provided (an initial value for all six state variables). Providing initial state information is well understood in the art. As one example, the termination might be placed in an initial "zeroing" fixture. After it is zeroed the cable to which the termination is connected would
440 then be lifted by a boom on a crane and swung into service moving a payload.

The IMS is not limited to any particular kind of system. Such systems have traditionally used spinning gyroscopes in combination with linear accelerometers. However, since space will be somewhat limited inside the termination, solid state solutions are preferable. The preferred embodiments will likely employ "ring laser gyros." As those

445 skilled in the art will know, these devices are not gyros at all. Rather, each individual ring laser measures interference between counter-propagating laser beams to sense angular velocity. Mathematical functions are used to convert the angular velocity to angular position. Where less accuracy is required, MEMS devices (micro electromechanical systems) may be used for monitoring the roll, pitch, and yaw motion.

450 Linear accelerometers (essentially very accurate force detectors) are used to measure linear acceleration that is then integrated to determine position (X, Y, and Z). Where high accuracy is needed, three orthogonal ring laser assemblies are used and multiple linear accelerometers are used. The IMS generally contains its own internal processor and memory. These units integrate the received data to produce values for the six state variables.
455 Alternatively, raw data may be fed from the IMS to the processor and the processor may perform the integrating functions.

The reader should bear in mind that not all inventive embodiments will include a full six degree of freedom IMS. As an example, some embodiments may provide only positional data without any attitude data. Others may provide attitude data with no reference to
460 position. Still others may omit an IMS altogether.

Multiple input/output ports 114, 116, 118, 126 are provided for the processor. I/O port 114 provides connection to communication connector 108. In this example the communication connector provides a hard-wired connecting to the far end of the cable. If, for example, the cable is being paid off a shipboard crane, the far end of the cable will remain
465 on the ship and the communication connector will allow real-time communication between the ship and the termination (even though the termination may be thousands of meters below the ocean's surface).

I/O port 116 connects processor 102 to acoustic transducer 112. The acoustic transducer is connected to acoustic antenna 110. This is a device intended for undersea
470 communications. It allows sonar-like signals to be sent by the termination to other devices. The termination can also receive these signals from an external source. This type of communication device is merely an example, as it is one of many potential technologies that can be used to either transmit or receive information. As an example, for the standing rigging on a drag-line crane, the communication is preferably via radio signals and antenna
475 110 in that application would be an R/F antenna.

I/O port 118 connects the numerous load cells 120,122, 124 (feeding load data from the individual strands) to processor 102 (any type of load sensor may be substituted). I/O port 126 connects multiple sensors to the processor. In this example, it connects pressure sensor 128, temperature sensor 130, and salinity sensor 136. These are merely examples of the many forms of sensors that may be tied into the instrument package. These may reside within the housing or be separate. In some cases they may be entirely separate, such as those on the subsea infrastructure – and may simply communicate data to the instrument package.

Returning briefly to FIG. 8, the reader will note the numerous wire connections 92 to the core and to the load cells monitoring the strand loads. The processor is able to use these connections to monitor position and loading information and to send that data back to the far end of the cable through the electrical and/or optical connections in core 72. Of course if the termination is designed to be a standalone system without power and / or communication running down the cable, this data is simply stored for ship-side retrieval or transmitted on an as needed basis. Power in that case is handed via a sufficient local power source.

In the version shown in FIG. 9 the intelligent cable module is configured for deep water lifting operations. The exemplary termination is provided with a pair of thrusters that can provide limited positioning adjustment – controlling both the twist in the cable as it moves down the water column, and the positioning of the payload as it nears its point of connection on the sea floor. Thruster controller 134 controls the orientation and thrust provided by the thrusters. The thruster controller is integrated with processor 102 as shown.

FIG. 11 provides a perspective view of the completed termination with a series of thrusters 140 included. Each thruster may be independently pivoted about its trunnion mount 142. Each thruster may also be throttled and reversed in this embodiment. The orientation and affiliation of thrusters may vary widely, and may not necessarily be integral to the termination housing. For example these may be mounted to a large external frame. In other cases there may further be auxiliary thrusters or position orienting devices mounted to the actual payload.

FIG. 13 shows a view of the intelligent termination 132 attached to a representative payload 162 in a deep water lifting scenario. Lifting tang 164 on the payload is connected to the clevis assembly by a cross-pin. Cable 10 suspends the assembly from a crane located on a surface vessel. Thrusters 140 provide selective lateral and torsional mobility on the sea floor, as well as assuring that the cable is not twisted when traveling to and from the vessel

through the water column which has alternating currents. With synthetic fiber and hybrid ropes in particular, this is helpful in assuring that rope integrity remains intact.

510 Surface vessel crane control systems include stabilization functions that are generally referred to as “anti-heave” functions. These are designed to minimize wave-induced motion of the payload on the end of the cable. However, these anti-heave functions in the prior art have no useful information regarding the exact motion of the termination and its attached payload when at depth. Rather, they attempt to compensate using only information regarding
515 the motion of the surface vessel. This is a challenge when running in deep water. It is especially significant with the use of synthetic fibers as the delayed spring response is more difficult to predict. In the present invention (for embodiments including real-time data transmission), the termination can transmit accurate motion and position information which can then be used by the surface anti-heave systems or an inline device.

520 FIG. 10 shows another embodiment in which there is no communication through the cable. Extended housing 138 includes a larger cavity 86. A large battery 96 is provided in this cavity. The battery provides electrical power to the instrument packages, the load cells, and other items requiring electrical power. In this version the instrument packages are more akin to the “black box” of an aircraft (a flight data recorder). An external port (not shown) is
525 provided so that when the termination is brought in for service the battery can be recharged and the internally-stored data can be downloaded. Of course, non-wired options are also possible for the battery charging and data downloading (such as an inductive connection).

 Other components may be provided to proactively monitor the state of the load strands (as opposed to inferring their state from the loads applied to them). FIG. 12 shows an
530 embodiment in which strand 12 includes embedded sensing/communication elements 144. These elements are intended to be used in monitoring the condition of the cable (though they may possibly be used for communication as well). In the version shown, these elements are optical fibers that stretch from one end of the cable to the other. Light is applied to the far end of the cable. Sensor 146 measures the light transmitted and sensor lead 148 passes
535 through the loading stud to carry this information to the processor (sensor lead 150 carries the load cell information). The optical fibers are sized to break as the strand is over-stressed. Alternately if a strand is damaged or cut in operation the ceased light would indicate a potential hazard. A reduction in light transmission thereby indicates a cable overstress. This example is one of many possible configurations. Fiber optics could run through a jacket,

540 down the center of the rope, etc. Alternatively, the use of electrical conductors could carry a similar function – providing either strain or pass/fail criteria for damage to the cable. Importantly, in all cases the termination may aid in collecting or transmitting the relevant information to determine the health of the lifting cable. In the event of a sensed problem, it could further be used to communicate the hazard to the surface vessel and / or other subsea
545 equipment.

Most damage, especially with synthetic fiber cables, would occur in the last few meters of the cable (as it reaches the termination). This is generally due to the fact that ROVs would be operating in this area. Thus, in some embodiments the sensing/comm elements 144 may only be included in this portion of the cable. One approach is to embed a 20 meter loop
550 of conductive material and then monitor for breaks in this material (such as by monitoring for increased resistance).

The sensors and other components provided within the intelligent cable termination need not be connected directly to the termination itself. FIG. 14 illustrates a placement scenario where downward visibility is needed from payload 162. Camera 170 is mounted on
555 payload 162 in a position providing a good downward field of view. Cable 168 attaches to camera 172 and to connector 166 on intelligent cable termination 132. In this version, video data is fed into the instrument package(s) within the termination and then up cable 10 to a surface ship. The video data is used to guide the placement of the payload. The camera and cable may be left with the payload when the payload is released from intelligent cable
560 termination 132. Connector 166 may facilitate this detachment (by being designed to reliably pull free upon the application of a specified detachment force).

FIGs. 15 and 16 show still another embodiment in which ROV's (remotely operated vehicles) are used. It is common in undersea lifting operations to use ROV's to guide and place a payload. These ROV's are typically lowered and controlled using a cable other than
565 the cable used for lifting the payload. Many ROV's are lowered into a working position in a protective "ROV garage." The ROV garage may contain a tether connected to the ROV. The tether often pays off a reel as needed. The tether may carry electrical power, bidirectional data signals, and air or fluid pressure. In recent years autonomous underwater vehicles ("AUV's") are replacing ROV's in some applications. In this disclosure, the term "ROV"
570 shall be understood to encompass both ROV's and AUV's. An AUV does not usually have a tether but it may still be deployed from a garage and it is often charged in that garage.

FIG. 15 shows an embodiment in which two ROV garages 172, 176 are connected to intelligent cable termination 132. Each ROV garage contains an ROV 174, 178. Using this system, the ROV's are lowered with the payload. The ROV's may be used to manipulate the position and orientation of the payload, as well as operating other systems such as the mechanism that releases the payload from the cable. The ROV's may also provide video data so that a surface operator can see the state of the payload and its surroundings.

FIG. 16 shows the same assembly with ROV 174 having left its garage 172. ROV 174 may be maneuvered as needed. It contains multiple thrusters that allow it to orient itself in a desired direction and provide force in a desired direction. Information regarding the state of the ROV may be sent via tether 180 back to ROV garage 172. This information may then be fed into the instrument package(s) within intelligent cable termination 132 (and possibly back up cable 10).

It is also possible to establish communications directly between the payload and the intelligent cable termination. In the version of FIG. 16, electrical cable 184 connects connector 182 on the termination to connector 186 on the payload. If, for example, the payload contains a release mechanism, this connection may be used to instruct the payload to release itself from intelligent cable termination 132. Cable 184 would then detach itself as the intelligent cable termination is lifted away from the payload.

FIG. 17 depicts a more common configuration for a payload. In this version payload 162 rests atop a standard pallet 194 with four legs 196. Rigging is used to appropriately suspend the load. In this case four slings 190 extend along the sides of the payload and down to the pallet. The four slings are joined to tang 188, which is connected to the intelligent cable termination. Release mechanism 192 is provided to selectively release tang 188.

When the assembly reaches its destination (such as the seabed), release mechanism 192 is actuated and the tang and slings fall free from the intelligent cable termination. The release mechanism may be actuated by an instrument package in the termination. Alternatively, it may be released by an ROV. The rigging may remain with the payload indefinitely. In the alternative, an ROV can be used to detach and retrieve the rigging.

As explained initially, an inventive intelligent cable module can be provided at any desired point along the cable. The preceding examples have been located near the end of a cable. In the following examples an intelligent cable termination is provided at some point in between a cable's terminations.

FIG. 18 shows an elevation view of a 12-strand braided cable. The individual strands
605 12 are interwoven to create the pattern shown. As those skilled in the art will know, it is possible to loosen the construction of such a cable in order to provide access to the cable's interior. This process is used when weaving a length of cable back into itself to form an eye (see, for example, commonly owned U.S. Patent No. 9,791,337).

FIG. 19 shows the cable of FIG. 18 after the strands have been loosened to reveal
610 central void 198 within the cable. Many individual inter-strand voids 200 are also created by the loosening process. FIG. 20 shows an embodiment of an intelligent cable module configured for insertion into the center of a braided cable. Intelligent cable module 202 has a smoothly shaped module casing 208. In this version communication strand 204 runs down the center of a braided cable. A connector 206 is provided on each end of module casing 208.
615 These connectors connect the devices within module casing 208 to communication strand 204.

Module casing 208 typically contains a processor and other associated digital devices – such as shown in the diagram of FIG. 9. FIG. 21 shows a view of intelligent cable module 202 installed within cable 10. The cable is cut away in the view (in the vicinity of the
620 intelligent module). Communication strand 204 passes down the cable's core and connects to module casing 208. Multiple intelligent cable modules may be provided along the cable's length, with communication strand 204 providing communication between these modules and to devices external to the cable. Once the module is in place, the strands are laid over the module in the same configuration as the rest of the cable. The perimeter of the cable is
625 shown in a phantom line in the view (bulging portion 210). From the cable's exterior, a bulge is evident in the vicinity of the intelligent cable module. However, the intelligent cable module itself is protected within the strands.

There are several ways in which an intelligent cable module such as shown in FIG. 21 can be installed. One approach is to install the module(s) at the time the cable is created. A
630 cable braiding machine creates a braid of strands around a core. In some cases the core is empty (a spacing mandrel may be used during the manufacturing process). In other cases the core contains a "filler" strand. Communication strand can be fed into the core as the braid is created. Module casings can also be added at desired intervals. In this case it may be necessary to modify the braiding machine to have a larger core diameter in the vicinity of the
635 intelligent cable module.

A second approach to installing an intelligent cable module is to add the module after the cable has been braided together with communication strand 204 at the core. FIG. 26 shows cable 10 with the strands urged apart to reveal the interior void. A portion of communication strand 204 is exposed and then cut to leave two cut ends as shown. 640 Communication strand 204 in this case is a simple bundle of electrical conductors in a jacket. Each of the conductors is made part of a connector 206 (such as shown in FIG. 21) and then slipped back into the void inside the cable. An intelligent cable module is slipped into the void as well, and the two connectors are then attached to the module to create an assembly such as shown in FIG. 21.

645 One of the issues with an assembly such as shown in FIG. 21 is the tendency of the intelligent cable module to move longitudinally within the cable's core. Other components may be added to fix its position. FIG. 22 shows the assembly of FIG. 21 with the addition of a pair of clamping collars 212. Each clamping collar 212 is a split collar that clamps to the cable's exterior. The two clamping collars may be joined by a protective cover 214. Cover 650 214 keeps the two clamping collars from moving away from each other. The result is that module casing 208 is trapped between the two clamping collars.

FIG. 23 shows another approach to maintaining the longitudinal position of the intelligent cable module. In this embodiment module casing 208 features an array of radial prongs 214. These protrude outward. Returning briefly to FIG. 18, the reader will note how 655 the braided strands 12 have intersections at regular intervals both laterally and longitudinally. FIG. 19 shows how the strands can be urged apart. Once the module casing 208 is placed into the interior of the cable, tension is placed on the cable gradually and each radial prong 214 is urged into the intersection of two adjacent strands. When additional tension is added the strands will grow taut around module casing 208. The module casing 208 is then held in 660 place via the fact that each radial prong is engaging the strands passing over the exterior of the module casing.

Once module casing 208 is secured in the cable's interior, inward pressure on the module casing can be correlated to cable tension. Thus, it is possible to measure tension at intermediate points along the length of the cable without interrupting any of the cable's 665 strands.

FIG. 24 shows another embodiment for the intelligent cable module. In this version the module is split into two halves 216, 218 that are clamped over the cable's exterior. This

embodiment is configured for use on a fixed cable for a dragline crane. The intelligent cable module contains tension monitoring instruments and a processor (with components similar to those depicted in FIG. 9). However, because this example operates in air, radio communication is preferred. Antenna 220 is provided on the module's exterior. This sends and receives radio signals.

In some applications a single cable will have multiple intelligent cable modules. FIG. 25 shows a single cable extending from a crane on board vessel 224 to payload 162 near the sea floor. Multiple intelligent cable modules 202 are installed along the length of the cable. The density of modules is varied in this example, with more modules being provided adjacent to the payload.

In some embodiments it is desirable to provide tension information for each strand at an intermediate point in the cable. FIGs. 27-28 depict an embodiment of an intelligent cable termination configured for this application. Intelligent cable termination 202 is shown in an exploded state. Housing 230 contains first instrument package 88, along with a processor, connectors, and communication hardware (such as depicted in FIG. 9).

As for the example of FIG. 1, cable 10 includes multiple individual strands. Each strand is attached to a strand termination 30. The strand terminations 30 on the right side in the view are attached to collector 34. The attachment for each strand includes load cells that monitor the tension on the strand.

The strands on the left side of the view are attached to strand terminations 30', and these are attached to collector 34'. Housing 230 and collector 34' include an array of through holes 226. The components shown are secured together by passing bolts 80 through holes 226 and then applying and tightening nuts 228. This draws housing 230, collector 34, and collector 34' tightly together. Middle strand collector 64 is then secured to collector 34 and middle strand collector 34' is secured to collector 34'.

The result is an intelligent cable termination 202 in the middle of a cable that can monitor tension on each individual strand and transmit that information to an external monitoring system (or record it for future retrieval). FIG. 28 shows a cable 10 with two intelligent cable modules 202 installed. In reality the two modules may be quite far apart (such as 1 km).

Returning to FIG. 25 the reader will recall that multiple intelligent cable modules may be present in a given installation (including multiple modules on multiple cables). These may

700 be organized as network nodes. FIG. 29 shows an exemplary embodiment in which controlling computer 234 communicates directly with master nodes 230. Each master node 230 then communicates with several nodes 232.

It is also possible to use a peer-to-peer network. FIG. 30 shows such a network in which multiple users (directly or indirectly) access a sensor network as embodied in the
705 intelligent cable modules. Such a network can be a mobile ad hoc network (“MANET”) where nodes come and go depending on availability. Consider for example the depiction in FIG. 25. Communication in this example can be via sonic pulses. Those modules near the bottom may have good communication with the payload while the surface vessel does not. In a MANET each node can be configured to disseminate information to other available nodes,
710 which then further disseminate the information. In this way information could be conveyed back up to the surface.

Another good example is found in offshore mooring operations such as are used for oil drilling platforms. In a common configuration 16 separate mooring lines extend from the floating platform down to anchors on the sea floor. These mooring lines are tightened until
715 the platform reaches a desired level of stability. If such cables include intelligent cable modules then a network will not normally be confined to a single cable. Rather, the network may include all modules in all 16 cables. If a MANET is used then a module in one cable may have a stronger communication link with a module in a second cable instead of another module within the same cable (particularly if sound pulses are used for communication).
720 Modules in different cables can then relay messages back and forth to create a robust communication network.

FIGs. 31 and 32 depict still another application for intelligent cable modules. FIG. 31 shows a large vessel 240 moored alongside a quay. Multiple mooring lines 244 locate the vessel with respect to the quay by securing it against mooring stay 250. Each mooring line
725 includes a sling 246 configured to encircle a bollard 242 on the quay. The shipboard end of each mooring line is attached to a winch that can be controlled to apply tension as necessary. The mooring lines travel with the vessel. They are an expensive piece of hardware that must be inspected, maintained, and periodically replaced. At present they are just visually inspected.

730 In the example of FIG. 31, intelligent cable module 292 has been added to the transition 248 between mooring line 244 and sling 246. This module can be configured to

measure and transmit many different values, including (1) simple tension on the mooring line, (2) the “pinching” force imparted by the diverging legs of the sling, (3) motion of the module (via an on board 3-axis or greater measurement system, (4) the number of loading cycles, and (5) ambient conditions such as temperature and humidity.

FIG. 32 shows a plan view of the configuration of FIG. 31. The shipboard end of each mooring line 244 is connected to a separate winch 254 on board the vessel. The shore end of each mooring line is connected to a bollard on quay 252. Controller 256 adjusts the tension on each mooring line (via its associated winch) to hold the vessel properly positioned against mooring stay 250. Such automatic tensioning systems are known in the art. However, such prior art systems do not incorporate an intelligent cable module to monitor the condition of each mooring line.

The present inventive system preferably includes an intelligent cable module on each mooring line. These modules provide data (directly or via periodic downloads) to a remote processor which then assembles the data and presents it to a user. The user interface can assume many forms. FIG. 35 provides a simplified depiction of such an interface. Monitor 270 presents a conventional windows-type display 272. The display includes an identification of a particular mooring line selected by the user (line identification data 274). The display also provides a list of significant parameters concerning the selected line (monitoring parameters 276). In this specific example the monitoring parameters are:

1. The number of mooring cycles in which the line has been used;
2. The number of fatigue load cycles (meaning the number of instances in which the load on the mooring line has exceeded a defined fatigue load threshold for the type of line in question);
3. The total load cycles for the line;
4. The peak load that has been placed on the line; and
5. A derived value for the number of mooring cycles remaining for the line.

Many other parameters could be stored and displayed. The data selected will vary with the application. The user interface preferably includes the ability for the user to make selections. As an example, for each parameter displayed the user could select the parameter and see more information. The user could be allowed, for example, to pull up a plot of peak loading cycles over time.

The previous examples have pertained to large, multi-stranded cables. The invention is by no means limited to such large cables and may in fact be applied to small cables as well. FIGs. 33 and 34 provide an example of an application for a cable that is smaller than a mooring line.

In the example of FIG. 33, cable 10 consists of a single strand (though that strand may still be a complex braided or twisting construction and may still incorporate a jacket). Anchor 260 is affixed to an end of cable 10 to create termination 258. Loading flange 262 is provided on anchor 260. The anchor is designed to rest in a hole through a plate. Loading flange 262 transmits load from the anchor to the plate. An intelligent cable module is located within anchor 260. It transmits radio frequency signals using antenna 264.

FIG. 34 shows a sectional elevation view through the assembly of FIG. 33. Anchor 260 is affixed to cable 10 in this example by potting. A length of filaments near the end of the cable are placed within a hollow passage through the anchor's interior. The filaments are then splayed apart. Liquid potting compound is added to the splayed filaments (either before or after they are placed in the anchor's cavity). The term "potting compound" means any substance which transitions from a liquid to a solid over time. A two-part epoxy is an example of a potting compound. Once the potting compound solidifies, the length of filaments within the anchor cavity is mechanically linked to the anchor. Potting transition 278 represents the transition from a composite mass of filaments locked within solidified potting compound to the freely flexing filaments within the cable.

In this example additional operations are performed before the potting compound is added. First, one or more strain gauges 266 are adhered to the interior wall of the anchor (within the hollow central cavity). Strain gauge 266 is connected to intelligent cable module 202 by electrical connection 268. The filaments near the end of cable 10 are placed within the cavity in the anchor and splayed apart. The filaments only extend up to filament limit 280. Above that level the anchor's interior cavity is empty volume. Intelligent cable module 202 is suspended in this empty volume. Potting compound is then added until it (1) saturates all the filaments, and (2) covers some or all of intelligent cable module 202. The potting compound then solidifies to create a unified assembly (Note that the order of operations can be varied while still producing the same result).

Once the potting compound is cured the example of FIG. 34 can be placed into service. Strain gauge 266 monitors the amount of elastic wall deformation of the anchor, and

795 this value can be correlated to the tension on cable 10. Provide the correlation is performed properly, the strain gauge reading will very accurately provide the tension on the cable. The tension values may then be stored within intelligent cable module 202 and/or sent out to a separate control system.

In some installations, many such assemblies may form part of a larger system. For
800 such an example, intelligent cable module 202 can be programmed to send a radio signal only in the event of an “exceedance.” An exceedance means an instance in which the cable tension has exceeded a defined warning limit.

Having described some embodiments in detail the disclosure will now turn to more general concepts regarding the invention and its applications. This invention may be said to
805 apply to the “Internet of Things” (“Iot”). Applications include synthetic fiber tensile strength members, commonly referred to as fiber ropes, cables, tethers, cords, or tendons. It also covers hybrid strength members incorporating metal and/or composites, as well as round slings, wound slings, rope grommets, and synthetic fabric slings. (Collectively referred to as “rope/cable/tension member”). More specifically, this disclosure covers multiple concepts
810 for synthetic fiber-based strength member systems used principally in high capacity and/or performance critical applications in conjunction with a termination and/or electronic module – whereby many more intelligent and connected synthetic rope-system technologies and overall data accumulation, communication, networking systems can be made possible.

While traditional strength members are passive in nature, the present invention seeks
815 to collect important usage data – either directly or indirectly from the strength member and/or termination and/or connected module. Traditional strength members incorporating synthetic fiber can easily incorporate fiber optics, wires, hoses, and other means of communicating, powering, or transmitting. The traditional cable strength member can in fact include much more functionality than is presently included. This additional functionality enabled by
820 incorporating either a rope-affixed module, or a rigid body termination (of any design – hereinafter mechanical termination) that can serve as a stable junction point for connecting, harnessing, and/or transmitting, power, data, fluid transfer, etc. This functionality has not traditionally been included as part of a high-load structural element. For example, electro-mechanical and opto-mechanical umbilical cables are common industry products. However,
825 these umbilicals do not carry significant tensile loads. For example a fiber optic or electrical wire cable may commonly include a synthetic fiber to act as the load bearing element, but

this is only to support the fiber optic or electrical wire and not to support a significant external load.

Whether at the end of the fiber rope as part of a “termination” or simply a rope-
830 attached device, the concepts of the inventive intelligent cable module generally include a multifunctional rope module (or modules) that offers a wide range of data collection, storage, computation, machine interfacing, communication, and/or networking options. These functions turn traditionally passive strength members into intelligent data gathering and dissemination devices.

835 Current offshore lifting operations can be very challenging - especially when the operator needs to place a very large, complex and heavy module that can have a value of many millions of dollars to a positional accuracy of centimeters in water depths up to 3,000m or more. Typically the operators have to rely on secondary sensors that are not directly connected to the payload/lift line system (such as the use of separate remotely operated
840 vehicles, ROV’s). These secondary devices watch and sometimes physically guide the payload as it travels through the water column and is placed on the sea floor or connected to another structure already in location. Sometimes guide wires are also used. These are just some of the methods and tools used today.

The majority of lifting operations are monitored closely throughout the lifting
845 operation to ensure the process is effectively executed. In the case of offshore lifting using a crane on a vessel, the monitoring is achieved primarily by instrumentation located on the vessel lifting device such as the crane or winch system. There are many different types of sensors used to control the descent and recovery speed and landing of the payload. This also includes the motion reference sensors that control the winch and crane to reduce the effect of
850 vessel rolling and pitching motions on the payload. This technique is widely known as AHC (active heave compensation). It should be remembered that all of these sensors are located on the deployment vessel and all other external monitoring is carried out by secondary devices such as the ROV which require separate control systems and operators dedicated to this task. Occasionally the use of motion reference units are attached to the payload as a method of
855 monitoring the payload during descent. However there are many challenges in direct communications with these devices through the water column.

The simplest form of intelligent cable module is one that is passive and standalone. An example of this is where an internal battery, data processor, and transmitter are used.

Alternately of course these could be data storage devices. As is probably evident, these
860 devices could rest anywhere inside or outside a cable termination (or at some intermediate
point along the cable). In this example, a strain gauge, load cell, or series of devices are
added to the cable module to accurately monitor the load and/or peak stress conditions.

The cost of failure during offshore lifting operations creates a need to develop the
capability to record the operation at the interface point between the object under lift and the
865 lift line interface (an intelligent cable module proximate the hook termination). The module
effectively becomes the equivalent of a flight data recorder used in commercial aircraft. The
presence of the module will enable the operator to record the complete operation at the
payload. There are many reasons this would be advantageous including providing a better
understanding of the performance of the AHC systems, recording load swings and all changes
870 that related to the vessel systems and their impact on the payload. Examples of data using
integrated sensors or recorders are peak loads, load trends, stresses within the termination
(such as strand termination loads), payload pitch/yaw/roll, position, acceleration, pressure,
temperature, vibration, distance from another object, material contact point, etc. Position and
movement sensors could include multi-axis gyroscopes (whether of the physical or ring-laser
875 type), accelerometers, etc. If going into something such as a downhole tool or pipe as
another example it may include sensors that measure diameter, speed, distance, gases,
material composition, time, etc. It could include video of the operation as yet another
example, or use a 3D camera or ultra-sonic camera that can make certain measurements. Any
number of sensors could be utilized.

880 The intelligent cable module can also incorporate communication tools for more
automated operations. Examples for lifting could be a location/position pinger, light
transmitter, or other communication device for working with other devices or machines, such
as an ROV or AUV. In such a case, the ROV need not use a traditional vision or camera
system to do certain functions – it may be more easily automated as a machine-to-machine
885 method of communication. Such a tool could have significantly more precision and enable a
more autonomous operation on the sea floor when coupled with other technologies.

With such a device, there is also the opportunity to extend the capability of the
intelligent cable module to provide the services and capabilities of the ROV or other external
devices. For example the module may include a significant power source that can be used as

890 a charging station or outlet for ROVs or AUVs. This could have a significant impact of the amount of secondary equipment deployed during any offshore lifting operation.

In its most general state, what has been described in the preceding embodiments is an intelligent cable module for rope systems, which incorporate sensors, communication devices, and/or power in standalone form. These devices may be powered within the module
895 (such as with batteries for example), or alternately the power may come from a separate source. This could be for example a wire running up the fiber rope, or a wire ported out the anchor and run separately to a power source. While the latter configuration is clearly not preferable for offshore lifting, in other applications such as a structural pendant, this would often be the most preferred means of powering the termination module. Likewise, sensors or
900 communication devices are preferably mounted within a rigid housing. However, in some cases there may be some external affixation involved. For example a termination may include internal batteries but an external 3D camera or laser sensor mounted in a non-hazardous area.

The next level of sophistication is an “active” intelligent cable module. Such a
905 module can provide active data/power/communication, on a real-time basis, and/or be able to respond autonomously to certain conditions. For example an acoustic pinger may signal pressure achievement, depth, position, etc, for other machines/tools to operate a certain function. As an example where the termination module reacts to other devices, the termination hook or load pin may be released when receiving a signal from another
910 device/machine, or alternately a communicated signal from the operator above water.

As an example of the user interface for real-time data, a graphical user interface can present current loading and recent peak loading for every strand of a 12 strand rope. In this example each of the rope’s primary strands has a load cell, and connecting hardwiring to this termination provides a real-time health monitoring tool.

915 Any of the examples above may be further developed with the addition of active components whereby communication between machines (such as an AUV or other data collection devices) or the operator (such as the vessel crane operator or an ROV pilot), is made possible. This real time information coming from the termination module can be used to automate industrial processes, improve safety, operating speed, and provide system
920 integrity / health data.

In many cases in order to make real-time data, power, communication, or other capability a realistic possibility, it would be most advantageous to run these types of services inline with the high load tension member – as the lines are often quite long. Externally affixing or helically wrapping these components around the high load strength member is a possibility in certain static cases, such as structural pendants. However, a far preferred method where possible is to incorporate these service lines into the strength member itself. For the purpose of this disclosure, a “service line” is any line other than the strength member that is added to expand the service context of the strength member and termination – such as a fiber optic line used for communicating data from one intelligent cable module to the next in a string of interconnected mooring lines. Any number of service lines can be used to improve the capability of the termination and system as a whole.

How these service lines get included into the strength member is entirely dependent on the strength member construction and the application. For example a crane line that runs at very high loads around sheaves would require a different construction than a semi-static pendant line or offshore mooring rope that is nearly always linear. With this in mind, below are a few distinct possibilities for incorporating service lines into the strength member:

1. Fiber optics, fluid or pressure hoses, electrical wires, etc. – for data transfer, communication, gas or fluid exchange, etc.
2. Service lines externally affixed to the strength member
- 940 3. Service lines helically wrapped around the strength member
4. Service lines located in the center of the strength member
5. Service lines located in the center of one or some of the primary strands of the strength member (In a 12 strand braided rope this may be one line per 12 strands)
6. Service lines alongside the strands or in place of certain strands in the strength member.
- 945

In most cases additional armoring or components will be needed to either protect the service line within the strength member, or protect the strength member from wearing on the service lines. Referring back to the offshore lifting example, very high stresses will be placed both on the service lines and the interface between these lines and the fibers. This may commonly require careful engineering to ensure the service line does not get damaged in use or compromise the performance of the strength member.

950

One can easily envision the technology being used for more than monitoring health at the termination point to more holistically monitoring the tension member system as a whole. As one practical example, the wires, optics, or other communication devices previously
955 discussed may not be used necessarily for communicating to/from the termination, but rather monitoring the health or integrity of the strength member. In some cases, the intelligent cable module may also be beneficial as a receiver, collecting data from other nearby devices and communicating this data through the included service line. In such as case the high load
960 tension member becomes the hub for a greater network of devices, not just the strength member itself. This could be a string of rope products, or entirely other machines such as AUVs, a subsea station that needs to report real-time data, etc.

In the field of offshore lifting, this type of device may also be considered an active and instrumented hook. This type of arrangement would allow for continuous communication with the hook during deployment and recovery to collect and send data from
965 the hook to the operators on the vessel in real time. With the data from the hook in real time it would be possible to improve the AHC (active heave compensation) performance and reduce the actual load swings on the payload. This also gives the opportunity to monitor load positioning and many other instruments.

Yet another very powerful configuration based on the components above is the ability
970 for the fiber rope termination to become a production / service tool – a machine at the rope that includes many potential service functions. Referring back to the offshore lift example, now with a real-time data feed to the surface, and the ability to sense location/position/heading/etc, the incorporation of payload position thrusters (on or near the termination or payload) becomes a practical and unique option. Due to the ultra-low weight
975 of synthetics in water, the payload can more easily be manipulated in the water column. Further, the lack of line weight allows for more tooling to be added to the end of the rope, such as battery packs for ROV or AUV charging, an ROV garage, integrated tools with actuators, etc. For example, if thrusters are added to the termination to position payload, they may be powered internally by a battery source, since the fiber rope has displaced so much
980 mass in the steel-to-fiber conversion. Alternately, based on examples provided previously, power or other key service lines could be run down the strength member. Such a configuration can in some cases displace the current ROV configuration.

This active payload positioning becomes the next logical step for the concepts above. The intelligent cable module in this version is used to both gather important information and guide the payload. If thrusters are added to the termination module, they could be manually driven like the ROV's used in the process today, or fully automated like an AUV, where machine-to-machine communication can provide higher levels of production and safety. In the later example, communication between subsea machines may help to guide the payload into position, manipulate the payload, and/or make more automated connections possible.

The intelligent termination or module could include many forms of sensor technologies – creating near countless forms of data. Below are examples:

1. Movement / position / heading / G-shock / inertial sensors
2. Accelerometers
3. Magnetometers
4. Gyroscopes
5. GPS devices
6. TIMU devices
7. MEMS devices
8. Acoustic / Ultra-Sonic Sensors
9. Pressure Sensors (atmospheric, liquid, solid)
10. Strain Sensors
11. Load Sensors
12. Torque / Torsion Sensors
13. Humidity Sensors
14. Temperature Sensors
15. Proximity Sensors
16. Vision or Image Sensors (2D / 3D)
17. Relative Movement Sensors (3D camera, laser, etc)
18. Light Sensors (UV or other)
19. Distance / Displacement Measurement Sensors (laser, linear encoder, camera, radar, etc)
20. Rotary Sensors
21. Code Reader / OCR Sensors
22. Photoelectric Sensors

- 1015 23. Photomicro Sensors
 24. Fiber Optic Sensors
 25. Gas Sensors
 26. Flow / Micro-Flow Sensors
 27. Liquid Leakage Sensors
- 1020 28. Contact Sensors
 29. Dielectric Sensors
 30. Electrical Conduction / Resistance Sensors
 31. Data Transmission / Communication Examples
 32. Torque sensors for the cable as a whole or subcomponents thereof.
- 1025 The data communication to and from an intelligent cable module can assume many forms, including:
1. Wireless communications such as Wi-Fi, Bluetooth, Passive or Active RFID, Zigbee, BAW, LTE, LTE-Advanced, or other radio or micro waves. Cellular, satellite, acoustic energy, sonic, electromagnetic induction, free-space optical, radar, or other.
- 1030 2. Wired communications such as conductive elements, fiber optic elements, and the like.
3. The use of electronic or other data storage devices to store data for later retrieval.
- Data may be pushed / transmitted only, pulled / received only, or both. Transmit vs
- 1035 receive capability may vary depending on module capability and application needs. Rope modules can include one or multiple methods of data transmission / communication. In the case of a wireless design, the addition of a hardwired-access component will typically be preferred for items such as system redundancy, backup, big data transfer, programming, or debugging as examples.
- 1040 The intelligent cable modules can be powered by a wide variety of sources, including:
1. Stored / Battery Power: Batteries may be designed for inductive charging, regular replacement, or life-use. System may be designed for ultra-low power consumption so that multi-year life is possible.
2. Self energizing systems such as a power cell
- 1045 3. RFID or similar which is energized by another device

4. Trickle charge systems such as with solar, wind, or other small auxiliary device

5. Auxiliary battery that is used to charge primary battery and be removed

1050 While it is possible that the rope module (s) are always connected directly to a power source (such as at the end or with conductors running down or around the rope), it is most common that there will also be a local battery or storage. For example, wired power may be used to power tools or maintain charge. Battery or stored power will likely be common to maintain data integrity and operate light ongoing functions.

1055 The CPU or similar data-processing device(s), serves as the programmable device that can be used to define the module intelligence and logic. This includes managing information such as:

1. Global Positioning System (GPS) satellite receiver
2. Data input digitization
3. Data computation
- 1060 4. Data compression
5. Data encryption
6. Data storage
7. Module time / date stamp
8. Signal conditioning and processing (from various inputs such as sensors)
- 1065 9. Sending and receiving of defined information packages (ex: email alert, network communications whether packaged or real time, etc)
10. Measure defined limits (tension, pressure, shock, etc) – deploy reaction signals to adjacent tools or receivers for network communication.

1070 11. Determine light, sound and other operator or networking signals based on certain conditions (low battery, overused rope, etc)

12. Manage hibernate/sleep modes for low power consumption

13. Review the strand-integrity data (via fiber optics, conductive elements, etc)

The modules can incorporate different operator/system alerts, including:

1. Visual alerts such as a status light (see external display 222 in FIG. 27)
- 1075 The electronic design could take on countless shapes/forms, depending on desired function.
2. Colored stack/condition lights, pulsing light patterns to communicate different conditions, etc.

3. LCD or other electronic data panel on or near or insertable into the module
4. Acoustic alerts
5. Acoustic chirps or pings

The intelligent modules can achieve machine-to-machine interfacing in many different ways, including:

1. Machine-to-machine Interfacing
2. Laser, UV light, wireless or wired transmission, ultrasound, wireless, or other method to communicate to another machine or onto the data network for alarming the operator or larger piece of equipment as a whole
3. Communication to a smart tablet or the local network so that computers are able to transmit conditions (electronic stack lights for example, or signal to operate a separate machine function) to any location
4. Real-time communication, or conditional data-transmission around certain events (shock load, time interval, etc).

For the purpose of this overall disclosure, intelligence can come from many potential forms including some form of bodies that house sensors and allow data to be managed. Generally speaking, this may be within the end (termination point), or anywhere along the rope, or both. While a termination is often at the end and used to transmit a load with a load connection point (such as an eye, hook, or stop), a module / IoT module is any device that is connected to the rope assembly, regardless of proximity. While it may be in or around the termination, in many cases it is preferable to be along the rope to provide intelligence. An IoT module would not typically be used to transmit a load, although this can be made possible. One should assume that throughout this disclosure a termination or module, while having different end-purposes, should be considered synonymous in its ability to provide the disclosed smart services / intelligence. Some ropes need only a smart module, some need a smart termination, some need both. In many cases the smart module rest inside or is adjacent to the termination. While the early disclosure was more focused on the termination point, this section will detail other means by which a more universal module or modules can be considered as primary and/or secondary devices. They may be used in place of an intelligent termination or used to support such a device.

Variations for the intelligent cable module include:

1. An intelligent cable module can be applied (mounted/inserted/affixed)
 1110 anywhere on or within the rope or strands. This may be at the ends, in the midspan
 (anywhere along the rope), near one end, or in segments.

2. There may be one or several modules serving different functions or
 communicating with each other. A module need not have a CPU or be independent – it may
 serve to function as a web to support other more intelligent devices or one central device.

1115 3. A module in a termination may serve as an end-hub for several midspan
 modules that gather other data. The mid span modules may simply provide load, position,
 temperature – they may be sensors alone and be used to interface with a CPU (such as in the
 termination), or otherwise a hub for data transfer means to another source (such as when
 hardwired).

1120 An intelligent cable module can be connected to a cable in many different ways,
 including:

1. Mounted inside the rope
2. Mounted to the outside of the rope (in symmetrical or asymmetrical form)
3. Mounted to certain strands of the rope (such as inside each of the primary sub-
 1125 ropes)
4. Tethered to a rope as an attached node
5. Mounted on one or both ends of the rope
6. Mounted in one or both legs of a typical rope splice
7. Mounted in the thimble of a spliced termination
- 1130 8. Mounted inside or affixed to another form of termination
9. Mounted permanently to a rope (tamper resistant), or designed to universally
 attach or clip on/off

Multiple modules may also be present in a single location. FIG. 21 provides an
 example of a single module casing 208 placed in the center of a cable. In this instance the
 1135 cable shown is a braid of 12 separate strands. In some cases each of these strands will itself
 be a braid of 12 smaller sub-strands. A smaller module casing could be placed within each of
 the 12 strands by separating some of the sub-strands. Some of these modules can even
 incorporate a removable data cartridge.

The intelligent cable module may rest on a sacrificial tail alone (such as where one
 1140 end has a termination and the opposing end is later spliced into another rope). This

configuration could be used to make a passive rope intelligent. It also allows the intelligence to be calibrated to the rope in a factory-controlled setting.

Monitoring examples include:

1. Termination drops or max shock. Rate of shock, duty cycles, cut strands, rope modulus, rope dielectric properties, rope length change, etc. Boom jacks (machine shocking), resonation, natural frequency, rope or strand torque, rope or strand imbalance, rope diameter, helix change, rope near-sheave or related device via prox sensors. Period of connection to another device via dielectrics, etc. Chemical contamination, line security, temperature etc. Chemical exposure, strand integrity, rope life management.
 2. Cycle Counting: Using inertial module or a RFID or other position sensor to count machine cycles in a rope. For example a hoist device that goes up/down.
 3. Module to log hours via movement/load/etc. – record life/use. Data store/collect – then send package as needed.
 4. Appropriate connection and load rating: Used to detect and indicate whether the appropriate rope and hardware are being used for a certain job, such as a lifting sling and shackle combination.
 5. Chip or communicated data can signal operator or machine of any desired condition (load, depth, recommended operating hours, temperature overage, etc)
 6. LCD panel or nearby tablet could identify peak conditions for inspection / review of system health (rope life, max operational load received, loading cycle count, etc)
- Exemplary applications for the inventive intelligent cable modules include:
1. Crane / Winch lines (Offshore or land cranes, deep shaft mines, etc)
 2. Large Vessel Ship-to-Shore & Ship-to-Ship Moorings (L&G tankers, Barges, etc)
 3. Structural Boom Pendants (cranes, draglines, shovels, etc)
 4. Civil structures tendons (bridge stays, post tension concrete structures, cable-rebar systems, etc)
 5. Towing lines (commercial fishery lines, nets, etc)
 6. Bridals (trawl doors, lifting assemblies, etc)
 7. Floating structure moorings (oil platforms, vessels, windfarms, wave energy, commercial docks, boats, etc)
 8. Tie-downs (cargo, aircraft, earth anchors, utility securement, etc.)

9. Lifting or Towing Slings (heavy lift round slings, rope grommets or light factory fabric slings)

1175 10. The technology could also be deployed in miniature and/or simplified form into small cable assemblies, such as used in fitness equipment, aircraft control cables, automotive control cables, safety tethers, boat lifts, medical devices, etc.

1180 11. As covered throughout this disclosure, the intelligent module(s) and/or terminations will commonly be linked to a greater network of devices. In principal, the devices when linked in some way can be viewed as rope networking modules – turning a physical rope system into a digital tool by which entirely new service functions may be derived. For example, a vessel mooring system that has been digitized not only allows an operator to understand each individual unit, but also how the system as a whole is functioning as well as stress that is imparted to the winches and other vessel components. The series of
1185 ropes become an input for data that is valuable for the entire machine/operation.

12. On a mining dragline multiple modules may communicate with one central collection device. They may be hardwired or wirelessly linked.

1190 13. All rope-related devices on a machine or operation with intelligent cable modules could be linked to create a complete / closed loop data set to then perform more sophisticated analysis. For example, load long-range distribution and interaction amongst 4 boom supporting pendant cables can be assessed, or overall load across certain connected vessel mooring lines can be managed. One can use this macro-data to better manage the asset or field as a whole – not just each individual tension member.

1195 15. Just like that of an electrical system shown in the picture below, the rope network can be configured in many ways, such as spoke and hub, pier to pier, multi-hub with boosters, interconnected, work through a gateway IoT module, a hybrid, etc. This may be considered as a distributed sensing network, and include items such as a smart hub, a digitized operator tablet to perform certain functions. This may be a slave or master network design – depending on the data collected, pushed, or pulled, and the overall system goal.

1200 16. Scanners may be used to ping for data. Technologies such as RFID allow a passive system to ping the regional network to gather certain data. For example this may be a ping to communicate peak loads on an hourly basis, whereas other data is stored and removed in other ways.

1205 17. The network rope IoT devices may all be interconnected and/or independently designed to push data into the cloud or a local server for networking with other sites or locations worldwide. In other works, the network may then be used to even more broadly evaluate systems performance or activity of geographies, countries, companies, equipment types, operation types, etc. An organization may gain visibility on the company-wide performance of critical equipment or operations. Of relevance is that tension members (such as fiber ropes) generally communicate meaningful data for heavy industries as they represent activities performed (for example payload values, hours operated, etc). Being able to digitize and communicate data from tension members in big/heavy equipment and operations is valuable in many ways. Countless user interfaces and analyses of key performance metrics are possible.

1215 18. While much of the above would suggest broad distribution, in many cases the network may simply be a single operator interface, such as a ruggedized tablet that can be brought onto a particular site to monitor data in real time or extract historical / stored data on an as-needed bases. Additionally, these devices may be used to program or reprogram the networked modules.

1220 For the embodiments in which information is transmitted from the intelligent cable module up the cable, the reader should bear in mind that the extraction point for this information may be in different locations. The “payload end” of the cable is the end to which the termination is attached. A cable is often paid off a drum on a surface vessel. Information applied to the cable at the payload end must be extracted at some point distal to the payload end. This extraction point may simply be the opposite end of the cable. However, it may also be some intermediate point where the information carrying components of the cable depart the load carrying components.

One may make some generalizing statements regarding the invention that will be true for many embodiments:

1230 1. It is advisable to place the instrument package(s) above the payload release point. An objective of the present invention is to use the instrument package many times in the deployment of multiple payloads, so it is undesirable to place the instrument package in a position where it is difficult to “bring home” with the termination when the payload is released. The payload release point may be in the vicinity of the intelligent cable termination (as shown in FIG. 17). However, it may also be far below the termination. In

some instances the release mechanism may lie 20 meters below the termination. This will be true where long slings connect the termination to the payload and the release mechanism is located on the payload end of the long slings.

1240 2. For the versions incorporating force sensing devices (load cells, strain gauges, etc.), the instrument package may transmit the sensed forces directly or record them for subsequent transmission.

1245 3. The preferred embodiments will all include a processor and the ability to transmit digital signals. However, it is possible to implement the invention using only analog components and no processor. As an example, a very simple version might include only load cells, a local battery, and possibly an amplifier set in the integrated termination. These analog devices could then send analog signals directly up the cable and all the processing would be done outside of the integrated termination.

1250 4. The instrument package ideally includes an inertial measurement system. Such a system, combined with real-time (or near real-time) data transmission back to the surface, allows a surface operator to know the precise location and orientation of the integrated termination (and by inference the payload itself).

1255 5. The use of synthetic filaments in the cable provides a large weight saving in comparison to prior art steel cables. This weight savings allows additional weight to be carried at the termination (or in the vicinity thereof). Batteries may be added to the intelligent termination to provide an ample power source without having to send power down the cable. Data may still be send through the cable in this scenario, but the greater challenge of sending power through the cable would be avoided.

1260 6. The camera such as shown in FIG. 14 may be a stereo camera, a laser scanner, or some other suitable device capable of allowing the intelligent termination to “home” on a target. As an example, a visual fiducial might be provided as the desired placement point on an undersea platform. A stereo camera could be used to guide the payload onto this target. A 3D object could be used as a target for a laser scanner. The camera could also be provided on the intelligent termination itself (perhaps offset on a lateral boom).

1265 7. If a visual guidance system is provided then the inertial measurement system does not have to be terribly accurate. The inertial system may be used to get the payload “in the ballpark” and the visual guidance system could then take over for the final placement. The combination of the two systems allows for greater accuracy while holding down costs.

Many other features can be included with the inventive termination, including one or more of the following:

- 1270 1. The memory may be used to log strand loads for future analysis regarding needed cable maintenance and possible removal from service.
2. Communication and power wires may not travel through the core of the cable but rather may travel externally. As an example, they might be embedded in the cable's jacket or wrapped helically around the cable.
- 1275 3. The collector and housing could be made as one integral unit.
4. The instrument package functionality can be applied to a cable having only a single strand (rather than a multi-stranded cable incorporating a collector).
5. The instrument package may be included as part of a ruggedized ROV garage.

1280 Although the preceding description contains significant detail, it should not be construed as limiting the scope of the invention but rather as providing illustrations of the preferred embodiments of the invention. Those skilled in the art will be able to devise many other embodiments that carry out the present invention. Thus, the language used in the claims shall define the invention rather than the specific embodiments provided.

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1300 CLAIMS

- Claim 1. An integrated cable system with intelligent monitoring features, comprising:
- a. a multi-stranded cable including synthetic fibers, wherein a majority of a tensile load placed on said cable is carried by said synthetic fibers;
 - 1305 b. said cable including a payload end and an extraction point distal to said payload end;
 - c. an intelligent cable module connected to said cable;
 - d. said intelligent cable module, including an instrument package, said instrument package including a processor;
 - 1310 e. said instrument package including a plurality of load sensors for a plurality of said strands, with each of said load sensors being configured to measure a load on one of said strands; and
 - f. a communication link contained within said instrument package, wherein said communication link is configured to transmit information from said
 - 1315 processor.

- Claim 2. The integrated cable system as recited in claim 1, wherein:
- a. said instrument package includes a measurement system configured to determine a position and orientation of said intelligent cable module; and
 - 1320 b. said communication link is configured to transmit said position and orientation of said intelligent cable module.

- Claim 3. The integrated cable system as recited in claim 1, wherein said communication link comprises an electrical connection through said cable to an extraction
- 1325 point.

- Claim 4. The integrated cable system as recited in claim 2, wherein said communication link comprises an electrical connection through said cable to an extraction
- 1330 point.

- Claim 5. An integrated cable system as recited in claim 2, wherein said instrument package includes a plurality of ring laser assemblies.
- 1335 Claim 6. The integrated cable system as recited in claim 1, wherein said instrument package further comprises a memory.
- Claim 7. The integrated cable system as recited in claim 6, wherein said memory is configured to store information obtained from said load sensors.
- 1340 Claim 8. The integrated cable system as recited in claim 7, wherein said intelligent cable module further comprises a battery supplying power to said instrument package.
- 1345 Claim 9. The integrated cable system as recited in claim 1, wherein said intelligent cable module includes a memory for storing data.
- Claim 10. The integrated cable system as recited in claim 1, wherein a load sensor is provided for each strand.
- 1350 Claim 11. An integrated cable system with intelligent monitoring features, comprising:
- a. a multi-stranded cable including a payload end and a second end;
 - b. an intelligent cable module connected to said cable between said payload end and said second end;
 - 1355 c. said intelligent cable module including an instrument package, said instrument package including a processor;
 - d. said instrument package including a plurality of load sensors for a plurality of said strands, with each of said load sensors being configured to measure a load on one of said strands; and
 - 1360 e. a communication link contained within said instrument package, wherein said communication link is configured to transmit information from said processor.

- 1365 Claim 12. The integrated cable system as recited in claim 11, wherein:
- a. said instrument package includes a measurement system configured to
 determine a position and orientation of said intelligent cable module; and
- b. said communication link is configured to transmit said position and
 orientation of said intelligent cable module.
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- Claim 13. The integrated cable system as recited in claim 11, wherein said
 communication link comprises an electrical connection through said cable to
 an extraction point.
- 1375 Claim 14. The integrated cable system as recited in claim 12, wherein said
 communication link comprises an electrical connection through said cable to
 an extraction point.
- Claim 15. An integrated cable system as recited in claim 12, wherein said instrument
1380 package includes a plurality of ring laser assemblies.
- Claim 16. The integrated cable system as recited in claim 11, wherein said instrument
 package further comprises a memory.
- 1385 Claim 17. The integrated cable system as recited in claim 16, wherein said memory is
 configured to store information obtained from said load sensors.
- Claim 18. The integrated cable system as recited in claim 17, wherein said intelligent
 cable module further comprises a battery supplying power to said instrument
1390 package.
- Claim 19. The integrated cable system as recited in claim 11, wherein said intelligent
 cable module includes a memory for storing data.
- 1395 Claim 20. The integrated cable system as recited in claim 11, wherein a load sensor is
 provided for each strand.