

# OPTICAL SENSING SYSTEM FOR WELLHEAD EQUIPMENT

## BACKGROUND OF THE INVENTION

The disclosed subject matter relates generally to subsea hydrocarbon production and, more particularly, to a subsea Christmas tree with condition monitoring.

5

In order to control a subsea well, a connection is established between the well and a monitoring and control station. The monitoring and control station may be located on a platform or floating vessel near the subsea installation, or alternatively in a more remote land station. The connection between the control station and the subsea installation is usually established by installing an umbilical between the two points. The umbilical may include hydraulic lines for supplying hydraulic fluid to various hydraulic actuators located on or near the well. The umbilical may also include electrical and or fiber optic lines for supplying electric power and also for communicating control signals and/or well data between the control station and the various monitoring and control devices located on or near the well.

15

Hydrocarbon production from the subsea well is controlled by a number of valves that are assembled into a unitary structure generally referred to as a Christmas tree. Christmas tree and wellhead systems have the principle functions of providing an interface to the in-well environment, allowing flow regulation and measurement, and permitting intervention on the well or downhole systems during the operational life of the well. The actuation of the valves in the Christmas tree is normally provided using hydraulic fluid to power hydraulic actuators that operate the valves. Hydraulic fluid is normally supplied through an umbilical running from a remote station located on a vessel or platform at the surface. Alternative systems using electrically based actuators are also possible.

25

In addition to the flow control valves and actuators, a number of sensors and detectors are commonly employed in subsea systems to monitor the state of the system and the flow of hydrocarbons from the well. Often a number of sensors, detectors and/or actuators are also located downhole. All these devices are controlled and/or monitored by a dedicated control system, which is usually housed in the remote control module. Control signals and well data are also exchanged through the umbilical.

30

Conventional Christmas trees typically only have a few sensors designed to provide information on the production process. These sensors fail to provide any information regarding the operation or efficiency of the Christmas tree or wellhead. If a particular sensor fails to operate accurately, it may provide errant information regarding the production process. Uncertainties in the accuracy of the well monitoring and the limited amount of data make it difficult to optimize the production process or to predict impending failures.

This section of this document is intended to introduce various aspects of art that may be related to various aspects of the disclosed subject matter described and/or claimed below. This section provides background information to facilitate a better understanding of the various aspects of the disclosed subject matter. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art. The disclosed subject matter is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

## **BRIEF SUMMARY OF THE INVENTION**

The following presents a simplified summary of the disclosed subject matter in order to provide a basic understanding of some aspects of the disclosed subject matter. This summary is not an exhaustive overview of the disclosed subject matter. It is not intended to identify key or critical elements of the disclosed subject matter or to delineate the scope of the disclosed subject matter. Its sole purpose is to present some concepts in a simplified form as a prelude to the more detailed description that is discussed later.

One aspect of the disclosed subject matter is seen in a method for monitoring a Christmas tree assembly installed on a subsea hydrocarbon well. The method includes providing an optical feedthrough module operable to communicate through a pressure boundary of the Christmas tree assembly at least one optical signal with a plurality of optical sensors disposed within the Christmas tree assembly for measuring parameters associated with the Christmas tree assembly. A health metric is determined for the Christmas tree assembly based on the parameters measured by the plurality of optical sensors. A problem condition with the Christmas tree assembly is identified based on the determined health metric.

Another aspect of the disclosed subject matter is seen a system including a Christmas tree assembly mounted to a hydrocarbon well, an optical feedthrough module, and a plurality of optical sensors. The optical feedthrough module is operable to communicate through a pressure boundary of the Christmas tree assembly. The plurality of optical sensors is disposed within the Christmas tree assembly for measuring parameters associated with the Christmas tree assembly and is operable to communicate through the optical feedthrough module.

### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The disclosed subject matter will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

Figure 1 is a simplified diagram of a subsea installation for hydrocarbon production;

Figure 2 is a perspective view of an exemplary Christmas tree in the system of Figure 1;

Figure 3 is a view of the Christmas tree of Figure 2 illustrating monitoring sensors;

Figure 4 is a simplified block diagram of a condition monitoring unit in the system of Figure 1;

Figure 5 is a simplified diagram illustrating how multiple or duplicative sensor data may be employed by the condition monitoring unit to identify problem conditions;

Figure 6 is a simplified diagram illustrating how optical sensors may be used to measure parameters of the Christmas tree of Figure 2; and

Figures 7-8 illustrate exemplary branching techniques that may be used for the optical sensors.

While the disclosed subject matter is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the disclosed subject matter to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosed subject matter as defined by the appended claims.

## DETAILED DESCRIPTION OF THE INVENTION

One or more specific embodiments of the disclosed subject matter will be described below. It is specifically intended that the disclosed subject matter not be limited to the  
5   embodiments and illustrations contained herein, but include modified forms of those  
embodiments including portions of the embodiments and combinations of elements of  
different embodiments as come within the scope of the following claims. It should be  
appreciated that in the development of any such actual implementation, as in any engineering  
or design project, numerous implementation-specific decisions must be made to achieve the  
10   developers' specific goals, such as compliance with system-related and business related  
constraints, which may vary from one implementation to another. Moreover, it should be  
appreciated that such a development effort might be complex and time consuming, but would  
nevertheless be a routine undertaking of design, fabrication, and manufacture for those of  
ordinary skill having the benefit of this disclosure. Nothing in this application is considered  
15   critical or essential to the disclosed subject matter unless explicitly indicated as being  
“critical” or “essential.”

The disclosed subject matter will now be described with reference to the attached  
figures. Various structures, systems and devices are schematically depicted in the drawings  
20   for purposes of explanation only and so as to not obscure the disclosed subject matter with  
details that are well known to those skilled in the art. Nevertheless, the attached drawings are  
included to describe and explain illustrative examples of the disclosed subject matter. The  
words and phrases used herein should be understood and interpreted to have a meaning  
consistent with the understanding of those words and phrases by those skilled in the relevant  
25   art. No special definition of a term or phrase, *i.e.*, a definition that is different from the  
ordinary and customary meaning as understood by those skilled in the art, is intended to be  
implied by consistent usage of the term or phrase herein. To the extent that a term or phrase  
is intended to have a special meaning, *i.e.*, a meaning other than that understood by skilled  
artisans, such a special definition will be expressly set forth in the specification in a defini-  
30   tional manner that directly and unequivocally provides the special definition for the term or  
phrase.

Referring now to the drawings wherein like reference numbers correspond to similar components throughout the several views and, specifically, referring to Figure 1, the disclosed subject matter shall be described in the context of a subsea installation 100 located on the seabed 110. The installation 100 includes a schematically depicted Christmas tree 120 mounted on a wellhead 130. The wellhead 130 is the uppermost part of a well (not shown) that extends down into the sea floor to a subterranean hydrocarbon formation. An umbilical cable 140 for communicating electrical signals, fiber optic signals, and/or hydraulic fluid extends from a vessel 150 to the Christmas tree 120. In other embodiments, the vessel 150 may be replaced by a floating platform or other such surface structure. In one illustrative embodiment, a flowline 160 also extends between the vessel 150 and the Christmas tree 120 for receiving hydrocarbon production from the well. In some cases, the flowline 160 and a communications line (not shown) may extend to a subsea manifold or to a land based processing facility. A topside control module (TCM) 170 is housed on the vessel 150 to allow oversight and control of the Christmas tree 120 by an operator. A condition monitoring unit 180 is provided for monitoring the operation of the Christmas tree 120.

Figure 2 illustrates a perspective view of an exemplary Christmas tree 120. The Christmas tree 120 illustrated in Figure 2 is provided for illustrative purposes, as the application of the present subject matter is not limited to a particular Christmas tree design or structure. The Christmas tree 120 includes a frame 200, a flowline connector 205, a composite valve block assembly 210, chokes 215, a production wing valve 220, flow loops 225, hydraulic actuators 230, a remotely operated vehicle (ROV) panel 235, a subsea control module (SCM) 240, and fluid sensors 245. Within the ROV panel 235, hydraulic actuator linear overrides 250 and ROV interface buckets 255 are provided for allowing the operation of the actuators 230 or other various valves and components by an ROV (not shown). Although certain embodiments described below employ components that are hydraulically operated, it is contemplated that corresponding electrically operated components may also be used.

The construct and operation of the components in the Christmas tree 120 are well known to those of ordinary skill in the art, so they are not described in detail herein. Generally, the flow of production fluid (*e.g.*, liquid or gas) through the flowline 160 is controlled by the production wing valve 220 and the chokes 215, which are positioned by manipulating the hydraulic actuators 230. The composite valve block assembly 210 provides

an interface for the umbilical 140 to allow electrical signals (*e.g.*, power and control) and hydraulic fluid to be communicated between the vessel 150 and the Christmas tree 120. The flow loops 225 and fluid sensors 245 are provided to allow characteristics of the production fluid to be measured. The subsea control module (SCM) 240 is the control center of the Christmas tree 120, providing control signals for manipulating the various actuators and exchanging sensor data with the topside control module 170 on the vessel 150.

The functionality of the condition monitoring unit 180 may be implemented by the topside control module 170 or the subsea control module 240 (*i.e.*, as indicated by the phantom lines in Figure 1. The condition monitoring unit 180 may be implemented using dedicated hardware in the form of a processor or computer executing software, or the condition monitoring unit 180 may be implemented using software executing on shared computing resources. For example, the condition monitoring unit 180 may be implemented by the same computer that implements the topside control module 170 or the computer that implements the SCM 240.

Generally, the condition monitoring unit 180 monitors various parameters associated with the Christmas tree 120 to determine the “health” of the Christmas tree 120. The health information derived by the Christmas tree 120 includes overall health, component health, component operability, *etc.* Exemplary parameters that may be monitored include pressure, temperature, flow, vibration, corrosion, displacement, rotation, leak detection, erosion, sand, strain, and production fluid content and composition. To gather data regarding the parameters monitored, various sensors may be employed.

Figure 3 illustrates a diagram of the Christmas tree 120 showing various illustrative monitoring points. These monitoring points may be provided through the use of optical sensors as further described in reference to Figure 6. An exemplary, but not exhaustive, list of optical sensors is provided below. Also, various signals associated with the components (*e.g.*, motor current, voltage, vibration, or noise) may also be considered. As shown in Figure 3, a vibration sensor 300 may be provided for detecting vibration in the flowline 160. Fluid Monitoring sensors 310 may be provided for monitoring characteristics of the production fluid, such as pressure, temperature, oil in water concentration, chemical composition, *etc.* One or more leak detection sensors 320 may be provided for monitoring connection integrity. Erosion and/or corrosion sensors 330 may be provided in the flow loops 225. Valve position

sensors 340, choke position sensors 350, and ROV panel position indicators 360 may be provided for monitoring the actual valve positions. Shear pin failure sensors 370 may be provided for monitoring the hydraulic actuators 230 and linear overrides 250. Other various component sensors 380 may also be provided for monitoring parameters, such as motor voltage, motor current, pump characteristics, *etc.* The sensors 300 – 380 may communicate through an optical feedthrough module 390 to the topside control module 170.

In general, the optical feedthrough module 390 is housed in a horizontal penetrator (shown in Figure 6) and provides an optical path between the Christmas tree 120 and the topside control module 170 and/or the condition monitoring unit 180. Although a horizontal penetrator is illustrated, it is also contemplated that a vertically oriented penetrator may also be employed. The optical feedthrough module 390 may take on various forms. In one embodiment, the optical feedthrough module 390 includes an optically transmissive window that includes optical repeaters on either side of the window that allow an optical signal to be communicated between entities inside the Christmas tree 120 pressure barrier to entities outside the pressure barrier. In the case of an optical window, no actual opening is defined in the pressure barrier. In another embodiment, the optical feedthrough module 390 may comprise a penetration that breaches the pressure boundary to allow an optical cable to pass through the housing.

In some embodiments, multiple sensors may be provided for measuring a particular parameter. For example, multiple voltage and current sensors may be provided to allow measurement of standard motor performance voltage and current as well as voltage or current surges, spikes, *etc.* The duplicate sensors provide both built in redundancy and a means for cross-checking sensor performance.

Figure 4 illustrates a simplified block diagram of an exemplary condition monitoring unit 180 that may be used in conjunction with the optical sensors described herein. The condition monitoring unit 180 includes a processing unit 400, a communications system 410, and a data warehouse 420. The condition monitoring unit 180 operates as a supervisory control and data acquisition (SCADA) system that accesses sensors, models, databases, and control and communications systems, as described in greater detail below. The condition monitoring unit 180 may consider one or more Christmas tree 120 or wellhead 130 related system performance or hydrocarbon production goals and access hydraulic, electronic, or

electrical Christmas tree 120 or wellhead 130 control devices to alter the operation of such devices, with minimal human intervention, in accordance with those goals.

The processing unit 400 may be a general purpose computer, such as a microprocessor, or a specialized processing device, such as an application specific integrates circuit (ASIC). The processing unit 400 receives data from a plurality of sensors 430, such as the sensors 300 – 370 shown in Figure 3, as well as other data. For example, one of the sensors 430 may provide motor current or voltage data. The processing unit 400 may operate directly on the sensor data in real time or may store the sensor data in the data warehouse 420 through the communications system 410 for offline analysis. Based on the sensor data, the processing unit 400 determines the health of the Christmas tree 120 and or the individual components (*e.g.*, valves, chokes, pumps, *etc.*). There are various techniques that the processing unit 400 may employ to determine health metrics. In a first embodiment, the processing unit 400 employs a condition monitoring model 440 that directly processes the data from the sensors 430 to determine a health metric. One type of model that may be used to determine a health metric for the Christmas tree 120 is a recursive principal components analysis (RPCA) model. Health metrics are calculated by comparing data for all parameters from the sensors to a model built from known-good data. The model may employ a hierarchy structure where parameters are grouped into related nodes. The sensor nodes are combined to generate higher level nodes. For example, data related to a common component (*e.g.*, valve, pump, or choke) or process (*e.g.*, production flow parameters) may be grouped into a higher level node, and nodes associated with the different components or processes may be further grouped into yet another higher node, leading up to an overall node that reflects the overall health of the Christmas tree 120. The nodes may be weighted based on perceived criticality in the system. Hence, a deviation detected on a component deemed important may be elevated based on the assigned weighting.

For an RPCA technique, as is well known in the art, a metric may be calculated for every node in the hierarchy, and is a positive number that quantitatively measures how far the value of that node is within or outside  $2.8\text{-}\sigma$  of the expected distribution. An overall combined index may be used to represent the overall health of the Christmas tree. The nodes of the hierarchy may include an overall node for the Christmas tree 120, multiblocks for parameter groups (*e.g.*, components or processes), and univariates for individual parameters.

These overall health metric and all intermediate results plus their residuals may be stored in the data warehouse 420 by the condition monitoring unit 180.

5 In another embodiment, the processing unit 400 employs one or more component models 450 and/or process models 460 that determine individual health metrics for the various components or the processes being controlled by the Christmas tree 120. The component models 450 may be provided by manufacturers of the particular components used in the Christmas tree 120. The outputs of the lower level health models 450, 460 may be provided to the condition monitoring model 440 for incorporation into an overall health  
10 metric for the Christmas tree 120.

The condition monitoring model 440 may also employ data other than the sensor data in determining the intermediate or overall health metrics. For example, real time production data 470 and/or historical data 480 (*e.g.*, regarding production or component operation) may  
15 also be employed in the condition monitoring model 440, component models 450, or process models 460. The historical data 480 may be employed to identify trends with a particular component.

The information derived from the condition monitoring model 440 and the nodes at  
20 the different hierarchy levels may be employed to troubleshoot current or predicted problems with the Christmas tree 120 or its individual components. The information may also be used to enhance hydrocarbon production by allowing the autonomous adjustment of control parameters to optimize one or more production goals. For example, the condition monitoring unit 180 may communicate to the system controls (*i.e.*, managed by the topside control  
25 module 170 and/or subsea control module 240) to automatically adjust one or more production parameters. The information may also be used to provide future operational recommendations for a component or system (*e.g.*, maintenance schedule, load, duty cycle, remaining service life, *etc.*). Rules based on the determined metrics may be used to facilitate these predictions.

30

The condition monitoring unit 180 may generate alarms when a particular component or process exceeds an alarm threshold based on the determined health metric. For example, alarm conditions may be defined for one or more nodes in the hierarchy. These alarm conditions may be selected to indicate a deviation from an allowed condition and/or a data

trend that predicts an impending deviation, damage, or failure. The alarm condition information may be communicated by the communications system 410 to operations personnel (*e.g.*, visual indicator, electronic message, *etc.*). The operation personnel may access the data warehouse 420 to gather additional information regarding the particular  
5 condition that gave rise to the alarm condition.

In one embodiment, the condition monitoring unit 180 employs the models 440, 450, 460 and/or data from each sensor and associated duplicate sensors to validate the functionality and status of the individual sensor systems or record an error or data offset. The  
10 condition monitoring unit 180 may employ adaptive techniques to account for detected variances in the sensor systems. The validated sensor data from a component, such as a choke 215, is used in the condition monitoring model 440 to confirm the functionality and status of the component. This validation enhances the reliability and accuracy of the hydrocarbon production parameters, such as temperature, flow, and pressure of the  
15 production fluid.

Figure 5 is a simplified diagram illustrating how multiple or duplicative sensor data may be employed by the condition monitoring unit 180 to identify problem conditions. At a first level, single sensor validation 500 may be performed (*i.e.*, sensor values are within  
20 permitted ranges). Redundant sensor validation 510 may be conducted at a second level based on the single sensor validation 500 to identify deviation information. For example, two independent sensors may be used to measure the same parameter (*e.g.*, pressure or temperature). Subsequently, multiple sensor validation 520 may be performed by comparing the sensor data from the redundant sensor validation 510 to data from other sources, such as  
25 other sensors, that provide an indication of the measured parameter. For example, pressure indications from a pressure sensor may or may not be consistent with expected values resulting from choke or valve position. The deviation and consistency information may be stored in the data warehouse 420. Moreover, the deviation and consistency information may be incorporated into the condition monitoring model 440 for health determination. Individual  
30 parameters may be within limits, but when considered from a deviation or consistency perspective, a problem condition may be suggested.

Referring now to Figure 6, a cross section view of a portion of the Christmas tree 120 is shown. A connector 600 couples the Christmas tree 120 to the wellhead 130. A tubing

hanger assembly 610 couples the Christmas tree 120 to the umbilical cable 140 (see Figure 1). A horizontal penetrator 630 is defined in the composite valve block assembly 210 to house the optical feedthrough module 390 (not shown). An optical cable 640 is coupled via a wetmate connector 650 to the optical feedthrough module 390 supported by the penetrator 630. An optical splitter 660 may be employed to route individual optical fibers 670 to optical sensors 680. The optical cable 640 may have multiple fibers 670, each serving one or more optical sensors 680.

As described above, the optical sensors 680 may be redundant to allow cross-referencing of sensor data to check sensor operability. The optical sensors 680 may monitor various aspects of the Christmas tree 120 as illustrated in Figure 3 (*e.g.*, the sensors 300-380). The term optical sensor 680 is intended to refer to a sensor communicating using an optical signal. The sensing portion of the optical sensor 680 may be optical in nature, but other types of sensors that have electrical or mechanical sensor elements and an interface that converts the data to an optical signal may also be used. Exemplary types of optical sensors include membrane deformation sensors, interferometric sensors, Bragg grating sensors, fluorescence sensors, Raman sensors, Brillouin sensors, evanescent wave sensors, surface plasma resonance sensors, total internal reflection fluorescence sensors, *etc.*

Although Figure 6 illustrates individual optical fibers 670 for each sensor 680, it is contemplated that one or more optical sensors 680 may be multiplexed on the same optical fiber. Hence, the optical splitter 660 may not be present in some embodiments. For example, as shown in Figure 7, an optical fiber 670 may be coupled to multiple optical sensors 680. Various multiplexing techniques may be used such as wavelength or time domain multiplexing. Figure 8 illustrates an optical network 800 that includes a plurality of optical fibers 670 and splitters 660 serving a plurality of optical sensors 680. Again multiplexing techniques may be employed to allow the sensors 680 to use the same fiber 670 for communication.

The optical feedthrough module 390 may support multiple channels achieved either by optical encoding, multiplexing, *etc.*, or by having multiple individual optical pathways or connections. The various optical network topologies illustrated in Figures 6-8 may be used with the multiple channel architecture. For example, the optical feedthrough module 390

may support a first channel to allow communication with components in the well 130 and support a second channel for communicating data associated with the Christmas tree 120.

5 The optical sensors 680 described in reference to Figures 3 and 6-8 may be used in conjunction with condition monitoring or independent of any condition monitoring.

Employing condition monitoring for the Christmas tree 120 and its associated components has numerous advantages. Operation of the well may be optimized. Current and future operability of the components may be determined and maintenance intervals may be  
10 determined based on actual component performance.

The particular embodiments disclosed above are illustrative only, as the disclosed subject matter may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no  
15 limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the disclosed subject matter. Accordingly, the protection sought herein is as set forth in the claims below.

## CLAIMS

### WE CLAIM:

1. A method for monitoring a Christmas tree assembly installed on a subsea hydrocarbon well, comprising:
  - 5 providing an optical feedthrough module operable to communicate through a pressure boundary of the Christmas tree assembly at least one optical signal with a plurality of optical sensors disposed within the Christmas tree assembly for measuring parameters associated with the Christmas tree assembly;
  - determining a health metric for the Christmas tree assembly based on the parameters
  - 10 measured by the plurality of optical sensors; and
  - identifying a problem condition with the Christmas tree assembly based on the determined health metric.
2. The method of claim 1, further comprising identifying the problem condition
- 15 responsive to the determined health metric deviating from a predetermined range of acceptable values.
3. The method of claim 1, wherein determining the health metric comprises employing a condition monitoring model of the Christmas tree assembly to evaluate the
- 20 plurality of parameters.
4. The method of claim 3, further comprising employing the condition monitoring model based on the plurality of parameters and historical data associated with at least one of the parameters.
- 25
5. The method of claim 3, further comprising employing the condition monitoring model based on the plurality of parameters and production data associated with the Christmas tree assembly.
- 30
6. The method of claim 1, wherein determining the health metric comprises employing at least one component model associated with at least one component of the Christmas tree assembly in generating the health metric.

7. The method of claim 1, wherein determining the health metric comprises employing at least one process model associated with the operation of the Christmas tree assembly in generating the health metric.

5 8. The method of claim 1, wherein the Christmas tree includes first and second sensors operable to measure a selected one of the parameters, and identifying the problem condition further comprises identifying a deviation condition associated with the first and second sensors.

10 9. The method of claim 1, wherein the Christmas tree includes a first sensor operable to measure a first characteristic of the Christmas tree assembly and a second sensor operable to measure a second characteristic of the Christmas tree assembly, and identifying the problem condition further comprises identifying that the first characteristics is inconsistent with the second characteristic.

15 10. The method of claim 1, further comprising communicating the problem condition to an operator of the Christmas tree assembly.

20 11. The method of claim 1, wherein the Christmas tree assembly comprises a valve, and at least one of the parameters is associated with a position of the valve.

25 12. The method of claim 1, wherein the Christmas tree assembly is operable to control flow of a hydrocarbon fluid, and at least one of the parameters is associated with a parameter of the hydrocarbon fluid.

30 13. A system, comprising:

a Christmas tree assembly mounted to a hydrocarbon well;

an optical feedthrough module operable to communicate through a pressure boundary of the Christmas tree assembly; and

a plurality of optical sensors disposed within the Christmas tree assembly for measuring parameters associated with the Christmas tree assembly and operable to communicate through the optical feedthrough module.

14. The system of claim 13, wherein at least a first optical sensor is redundant to at least a second optical sensor.

15. The system of claim 13, further comprising:

5 a first optical cable coupled to the optical feedthrough module;

an optical splitter coupled to the first optical cable; and

a plurality of optical fibers coupled between the optical splitter and the plurality of optical sensors.

10 16. The system of claim 15, wherein at least one subset of the plurality of optical sensors are coupled to a first one of the optical fibers.

17. The system of claim 13, further comprising at least one optical fiber coupled between the optical feedthrough module and a subset of the plurality of optical sensors.

15 18. The system of claim 17, wherein the optical sensors in the subset are multiplexed on the optical fiber using at least one of wavelength multiplexing and time domain multiplexing.

20 19. The system of claim 13, further comprising a condition monitoring unit operable to determine a health metric for the Christmas tree assembly based on the parameters measured by the plurality of optical sensors and identify a problem condition with the Christmas tree assembly based on the determined health metric.

25 20. The system of claim 19, wherein the condition monitoring unit is operable to employ a condition monitoring model of the Christmas tree assembly to evaluate the plurality of parameters.

30 21. The system of claim 20, wherein the condition monitoring unit is operable to employ the condition monitoring model based on the plurality of parameters and historical data associated with at least one of the parameters.

22. The system of claim 20, wherein the condition monitoring unit is operable to employ the condition monitoring model based on the plurality of parameters and production data associated with the Christmas tree assembly.

5 23. The system of claim 19, wherein the condition monitoring unit is operable to employ at least one component model associated with at least one component of the Christmas tree assembly in generating the health metric.

10 24. The system of claim 19, wherein the condition monitoring unit is operable to employ at least one process model associated with the operation of the Christmas tree assembly in generating the health metric.

15 25. The system of claim 19, wherein the Christmas tree includes first and second optical sensors operable to measure a selected one of the parameters, and the condition monitoring unit is operable to identify a deviation condition associated with the first and second optical sensors.

20 26. The system of claim 19, wherein the Christmas tree includes a first optical sensor operable to measure a first characteristic of the Christmas tree assembly and a second optical sensor operable to measure a second characteristic of the Christmas tree assembly, and the condition monitoring unit is operable to identify that the first characteristics is inconsistent with the second characteristic.

25 27. The system of claim 19, wherein at least one of the optical sensors comprises a vibration sensor, a corrosion sensor, an erosion sensor, or a leak detection sensor.

28. The system of claim 19, wherein the Christmas tree assembly comprises a valve, and at least one of the optical sensors is associated with a position of the valve.

30 29. The system of claim 19, wherein the Christmas tree assembly is operable to control flow of a hydrocarbon fluid, and at least one of the sensors is operable to measure a parameter of the hydrocarbon fluid.