

PIPELINE ANALYSIS SYSTEMS

TECHNICAL FIELD

[001] The present disclosure relates to a system for the analysis of small diameter pipelines for, for example, wear, leaks, corrosion and other defects. More particularly, the present invention relates to, but is not limited to, systems for analysing the internal status of a small diameter pipeline during operation of the pipeline.

BACKGROUND

[002] Pipelines are a common conduit for transportation of liquids and/or gaseous products. They are important transportation infrastructure in numerous industries, such as oil & gas, chemical, pharmaceutical, and water industries.

[003] Leakage incidents in pipelines is a persistent concern for any pipeline operator. Pipeline deterioration through ageing is unavoidable and is accelerated through pipeline defects such as corrosion. Such incidents lead to loss and wastage of pipeline products and can even pose a serious safety hazard if the product is combustible. Large leaks are easy to detect as they cause a significant change in pressure and acoustic signature. On the other hand, small leaks are a challenge to detect as they only cause minute changes to the pressure and acoustic signature which can be difficult to spot. However, these minute leaks can still be dangerous, especially if the product is combustible. Given the integral nature of pipelines in the continued and proper functioning of businesses and the economy, maintaining the health and integrity of pipelines is vital.

[004] The ability to identify signs of deterioration in pipelines, such as precise locations where corrosion has taken place, is needed, so that suitable and timely preventive action can be taken before the defect leads to irreversible damage. However, existing methods are either highly labour-intensive (e.g. using visual inspection of the entire network) or cost-intensive (e.g. relying on a plurality of internal and/or external fixed sensors installed at regular intervals along the network).

[005] To collect more data on the condition of a small diameter pipelines (pipes or pipelines with a diameter between 100mm to 300mm), operators can install more in-situ sensors. However, this increases the cost of operational installation and maintenance, especially if a pipeline is operating in an isolated area.

[006] In addition, to monitor the condition of small diameter pipelines, deploying in-situ inspection systems is not feasible. Typically, the in-situ systems are designed for pipelines with

large diameter, which is generally above 300 mm. This can be due to such devices being propelled by the product flowing in the pipeline of large diameter pipes, and there being insufficient force, to propel the devices, applied by the flow of product in small diameter pipes.

[007] Given these limitations, the above-mentioned methods are unable to provide sufficiently accurate, timely and comprehensive data to enable pipeline operators to continuously monitor and assess the health of a pipeline network.

[008] In some instances, sensors are not used. Particularly for small diameter pipelines, conventional inspections are generally not done regularly.

[009] There are some autonomous systems for in-line health monitoring of large diameter pipelines. These systems range from traction wheel-based systems to fluid propelled systems. Various sensors can be installed on these systems to detect various abnormalities within the pipeline, such as corrosion, weld failures, free-spanning and leakage whilst moving through a pipe. However, these systems are generally designed for large diameter pipelines and cannot be easily used to inspect small diameter pipelines due to comparative design constraints for large diameter pipes.

[010] It is desirable therefore to provide a system that reduces or removes one or more of the abovementioned disadvantages with existing methods, or at least provides a useful alternative.

SUMMARY OF THE PRESENT DISCLOSURE

[011] Disclosed herein is a pipeline analysis system for analyzing a pipeline, comprising:

a housing;

at least one sensor connector at least partially within the housing, each sensor connector being for connecting to at least one sensor, each sensor being for capturing information about a portion of the pipeline; and

a plurality of supports for supporting the housing relative to an internal surface of the pipeline,

wherein at least one support of the plurality of supports has a collapsed condition, to reduce an overall cross-section of the system, and an extended condition to increase an overall cross-section of the system.

[012] In the extended condition, the plurality of supports may maintain the housing sufficiently centred in the pipeline such that information captured by each said sensor, at any angle around the system, is consistent. As used herein, the term "angle around the system" refers to an angle in a plane for which the longitudinal axis of the pipeline is a normal, and the information being "consistent" means that, regardless of that angle, the information captured

by the sensor(s) is similarly useful – e.g. at no angle is the information substantially more noisy than at any other angle, as a result of the distance at which the information is captured.

[013] The plurality of supports may comprise an extension sensor for measuring a difference in extension between the collapsed condition and extended condition.

[014] Each support of the plurality of supports may comprise a scissor-leg or a spring-loaded leg.

[015] The plurality of supports may comprise one or more motion sensors for measuring displacement of the system in the pipeline.

[016] The plurality of supports may comprise rotating members (e.g. wheels or rollers) for rolling along an internal surface of the pipeline, and the motion sensors may then measure rotation of the rotating members – e.g. to determine distance travelled, and differences between distance travelled of different rollers can determine when corners are being or have been traversed.

[017] The at least one support may be configured to move from the collapsed condition to the extended condition upon deployment of the system into the pipeline.

[018] The system may further comprise a tether. The tether may be connected to an external location (e.g. a fixed position, such as a lug, on the pipeline, or to a winch) to enable the system to be pulled from the pipeline. The tether may alternatively, or in addition, comprise a communication line for communicating with the system. The tether may communicate with the system through the tether connector.

[019] The system may further comprise an external sensor. The term "external" refers to being outside of the pipelines, such as an above-ground sensor located above-ground for underground pipelines, or a floating sensor for submerged pipelines. The external sensor tracks motion of the system in the pipeline.

[020] The pipeline may comprise a main pipe and a docking station connected to the main pipe and being of smaller diameter than the main pipe; and the plurality of supports may be configured to move from the extended condition to the collapsed condition to facilitate movement of the system into the docking station.

[021] The system may further comprise a functionality extender module adapted to be connected to the housing, with one or more sensor connectors of the at least one sensor connector being provided on the functionality extender module.

[022] The housing may comprise two opposed axial ends and the functionality extender module connects to a first end of the two opposed axial ends. The functionality extender module may be adapted to be connected to a further functionality extender module, wherein

one or more sensor connectors of the at least one sensor connector is provided on the further functionality extender module.

[023] The housing may comprise a tether connector for attaching to a, or the, tether by which the system can be retrieved from the pipeline. This tether connected to the housing may be used track the motion of the system inside the pipeline. The tether connector may be connectable or connected to the tether and the tether is connected to an external location, to facilitate retrieval of the system from the pipeline by the tether. The tether connector may be connectable or connected to the tether and the tether may comprise a communication line for communicating with the system (e.g. to receive, from the system, measurements from the sensor and to transmit those measurements to the external location or remote computer memory, or to transmit control signals to the system from that external location or remote computer memory). The tether connector may be connectable or connected to the tether and the tether may be configured to be used to track the motion of the system inside the pipeline.

[024] The system may further comprise a steering mechanism connected to the housing, for steering the system in the pipeline. The system may be propelled, in use, along the pipeline by fluid in the pipeline and the steering mechanism comprises one or more rudders to steer the system under fluid pressure. The steering mechanism may also, or instead, comprise one or more electromagnets, the one or more electromagnets being selectively activated to attract the system towards one side of the pipeline. The one or more magnets may comprise a plurality of magnets spaced about a circumference of the housing.

[025] The system may further comprise a memory device within the housing, the memory device being in communication with the at least one sensor connector to receive and store measurements taken by the at least one sensor when connected to the at least one sensor connector.

[026] A pipeline analysis system as described above, for analyzing a pipeline, may comprise a steering mechanism connected to the housing, for steering the system in the pipeline.

[027] The steering mechanism may comprise one or both of:

one or more rudders for steering the system under fluid pressure from fluid in the pipeline; and

one or more electromagnets, each electromagnet of the one or more electromagnets being selectively activated (i.e. able to be selectively activated) to attract the system towards one side of the pipeline.

[028] The system may further comprise:

a memory device within the housing; and

a position sensor connected to one of the at least one sensor connector,
the memory device storing a destination location and at least one of:
a pipeline network map; and
steering instructions, and
the steering mechanism automatically steering the system towards the destination location
in accordance with the pipeline network map or steering instructions, and measurements
taken by the position sensor.

[029] The system may further comprise:

a memory device within the housing; and
a position sensor connected to one of the at least one sensor connector;
wherein the memory device records a plurality of locations of the system as the system moves
in the pipeline.

[030] The system may further generate a pipeline network map from the plurality of
locations.

BRIEF DESCRIPTION OF THE DRAWINGS

[031] Some embodiments of a pipeline analysis system in accordance with present
teachings will now be described, by way of non-limiting example only, with reference to the
accompanying drawings in which:

FIG. 1 is an isometric view of a system in accordance with some embodiments;

FIG. 2 is a side view of the system of FIG. 4;

FIG. 3 shows a front view of the system of FIG. 1 – FIG 3(A), and a rear view of the
system of FIG. 1 – FIG. 3(B);

FIG. 4 is a schematic illustration of a closed-loop pipeline or pipe network;

FIG. 5 is a schematic illustration of an open-loop pipeline or pipe network;

FIG. 6 shows a front view of a system in accordance with some embodiments – FIG.
6(A), and a side view of the system of FIG. 6(A) – FIG. 6(B);

FIG. 7 provides various views of a system in accordance with present teachings,
navigating a 90° pipe bend; and

FIG. 8 represents a neural network structure for analysing audio signals from a
hydrophone sensor to detect abnormalities in a pipeline.

DETAILED DESCRIPTION

[032] In some embodiments, the invention is an autonomous pipeline prognosis, analysis or monitoring system that collects data on the structural condition of a pipeline and analyses its health status through a plethora of pipe inline data it collects. The design of the embodiments of the invention is modular, allowing easy switching of sensors and supports, or supporting structures, of different length to cater to pipelines of varying internal diameter and different media conveyed by the pipeline. In addition, embodiments of the present invention may autonomously take a pre-programmed route when faced with a branching pipeline. To allow on-the-fly deployment and data transference capabilities, the present invention may include docking infrastructure comprising one or more docking stations installed at strategic locations or pre-determined intervals along a pipeline or in a pipeline network.

[033] The invention is a simple to install and on-the-fly deployable device that can collect data about, for example, the structural integrity of a pipeline and parameters of interest of a product (e.g. gas, sewerage) flowing within the pipeline.

[034] Figure 1 shows a pipeline analysis system 100 in accordance with present teachings. The system 100 broadly comprises a housing 102, a plurality of sensor connectors 104 (there may, in other embodiments be a single sensor connector or more than one sensor connector), and a plurality of supports 106.

[035] The housing 102 can take various forms. Presently, the housing comprises two opposed end caps 108, 110. The end caps 108, 110 are aligned along the pipe (not shown) in use. The housing 102 also comprises a body 112 that is closed by the end caps 108, 110, containing circuitry and sensors. The body 112 is presently cylindrical, having a longitudinal axis X-X extending through the end caps 108, 110 and therefore aligned with the direction of travel of the system 100 through a pipe when in use.

[036] The body 112 is transparent. It may be made of Perspex, glass or another material. In practice, the housing 102 and each component of the system 100 can be fabricated from any suitable material – e.g. a material that will not react or otherwise interact with substances in the pipe. Presently, the transparency of the body 112 affords light transmission. This can be to aide penetration of light from sensors for image capture of the internal condition of a pipe, for infrared or other wavelength detection of parameters (e.g. cracks, smokiness etc) or, on retrieval of the system 100 from a pipe, for extracting data captured by the system 100.

[037] Each sensor connector 104 is for connecting to at least one sensor 114. The sensor connectors 104 enable data from the sensors 114 to be recorded and/or transmitted. The sensor connectors 104 may directly connect and support the sensors 114 in the housing 102 or may electrically connect to the sensors 114 that are themselves attached elsewhere in the

housing 102 – i.e. serve as a data port. Each sensor 114 captures information about a portion of the pipe (which may be interchangeably referred to as a pipeline). That information may be the cloudiness or air quality/composition of atmosphere within the pipe, structure of the pipe (e.g. image captured for crack detection), pressure, flow and various other parameters or characteristics.

[038] In some cases, sensors require direct exposure to the atmosphere surrounding the system 100. For example, sensors 116, 118 and 119 project through end cap 108 to gain direct exposure to the surroundings of the system 100. Those sensors 116, 118 and 119 extend through seals 120, 122 that seal the housing from the surrounds to which the sensors 116, 118 and 119 are exposed. In one embodiment, sensor 116 is a camera, sensor 118 is a temperature sensor and sensor 119 is a hydrophone.

[039] The plurality of supports 106 support the housing 102 relative to an internal surface (not shown) of the pipeline. With reference to Figure 2, each support 106 moves to maintain the housing 124 substantially in the centre of a pipeline. As used herein, the terms "substantially in the centre" or "in the centre", and similar, are intended to refer to the housing 124 being generally centrally located with regard to a longitudinal direction of the pipeline such that the sensors can capture consistent results about the structural condition of the pipeline at relevant locations around the system 132.

[040] At least one, and generally all, of the supports has a collapsed condition in which it is retracted back towards the housing to reduce the overall cross-section of the system relative to the cross-section of the pipeline, and an extended condition to increase the overall cross-section of the system. In this manner the system 132 can expand, by moving the supports to the extended condition, to bear against the internal surface of a larger pipe, and contract towards or to the collapsed condition to bear against the internal surface of a smaller pipe or for removal from the pipeline.

[041] The supports of the present embodiment include an extension sensor for measuring the difference in extension between the collapsed condition and extended condition. There may be an extension sensor for each support or, where supports are interconnected similar to supports 106a and 106b, a single extension sensor for each interconnected group of supports. The extension sensor may be an angle sensor built into or attached to a mount 126 of the support, or may result from measuring extension of the interconnecting member of an interconnected pair or group of supports – e.g. resilient member or spring 128.

[042] The present supports are spring-loaded, though scissor-leg configurations and others may be used to afford expandability and collapsibility depending on the design of the system

and its application. The supports may automatically move to the expanded condition upon deployment of the system 132 into a pipeline – e.g. upon powering up or switching on the system 132 – or may be expandable on supplying a control command using a controller housed in the housing 124.

[043] In some embodiments, the system will remain permanently in the pipeline. In other embodiments, the system will be removable. In the latter case, the system is deployed through a docking station. The pipeline comprises a main pipe (which may be the only pipe) and the docking station is connected to the main pipe. The docking station is of smaller diameter than the main pipe, or the same diameter, so that the system can be inserted into the docking station and deployed into the main pipe in the collapsed condition. The supports are then configured to move from the collapsed condition to the extended condition on deployment of the system from the docking station into the main pipe. Similarly, the supports are configured to move from the extended condition to the collapsed condition on return of the system from the main pipe into the docking station.

[044] Collapsed may be electronically controlled. In some embodiments, the system is attached to a tether 142 and the supports may then resile under biasing force from resilient members – e.g. member 128 – between collapsed and expanded conditions, and thus pulling the tether 142 will pull the system from the main pipe into the docking station and cause collapse of the supports to the collapsed condition.

[045] Each support comprises a rotating member such as a roller or wheel, for rolling along the internal surface of the pipeline. Support 106a comprises a rotation sensor 130 for measuring rotation of the rotating member of support 106a. The rotation sensor 130 can therefore determine this distance the support 106a, and thus the system 132, has travelled along the pipe. If support 106b, or other ones of the supports, were to also include a rotation sensor, the collective readings from the rotation sensors could be used to determine relative movement of the supports and therefore determine whether any one of the supports is slipping against the internal surface of the pipeline and whether the system 132 is travelling or has travelled around a bend or corner. The rotation sensor may be replaced by another form of motion sensor to capture displacement of the system 132 along the pipe, such as an image capture device where image comparison can be used to calculate displacement.

[046] The housing 124 comprises a shroud 134. The shroud 134 can be used to protect sensors projecting through the housing, but may also be used to support a functionality extender module connected to one of the axial ends 136, 138 of the housing 124. The shroud 134 also presently serves as a tether connector to anchor the tether 140 to the housing 124.

Where the system includes one or more functionality extender modules, the tether may instead be connected to one of those modules – e.g. the rearmost module. The tether connector is connected to the tether, in use, and the tether is connected to an external location, to facilitate retrieval of the system from the pipeline by the tether. The external location may simply be a lug, such as a lug mounted to the pipeline, so the tether can be pulled by an operator to retrieve the system from the pipeline. In some embodiments, the tether is connected to a winch (manual or automatic) that can be rotated to pull the system from the pipeline. Alternatively, or in addition, the tether can include a communication line for communicating with the system. To this end, the tether connector may comprise a communication plug through which data transferal between the tether and system (which in some embodiments comprises the tether and in other embodiments is considered a separate device or system from the tether) can take place. Thus, sensor measurements can be transferred from the system to the tether and from the tether to a remote computer memory or other external location for storage and/or analysis. The tether may also be configured to be used to track the motion of the system inside the pipeline. For example, a length of tether pulled into the pipeline by the system determines how far into the pipeline the system has travelled. The motion sensors (which may include one or more accelerometers) can determine turns and changes in elevation of the system. Thus, the distance and changes in direction and elevation can be used to determine or estimate the location of the system in the pipeline network and can facilitate mapping of the pipeline or pipeline network.

[047] The system may also include an external sensor 141 for tracking motion of the system in the pipeline. The external sensor 141 can either detect the location of the system wirelessly – e.g. using electromagnetic-field detection (where the device either has an electromagnetic field, or emits one), or a listening device or both – or, if connected via the tether 140 as shown, then location detection can occur via communication with the tether. Depth of the system can then be determined based on change in distance the system has travelled into the pipeline, coupled with changes in electromagnetic field or sound (i.e. the weaker the field or softer the sound, the further the system is from the sensor 141). The sensor may also have a movement mechanism, such as tracks 143, to manually or automatically follow the system – e.g. after determining the movement of the system, the sensor 141 may follow that movement to stay within range of the system.

[048] The aforementioned functionality extender module is adapted to be connected to the housing 134 and to include one or more sensor connectors to extend the functionality of the sensor or sensors within the housing 124. This enables the housing 124 to be generic and, for

example, to include some standard sensors or no sensors at all, and for the functionality module to provide a mechanism for additional sensors to be integrated into the system. Thus, a functionality extender module with specific sensors connections or arrangements can be selected to suit the particular monitoring task to which the system 132 will be put. The functionality extender module is connected along the longitudinal axis of the system. Thus the length of the overall system increases, but the diameter of pipeline through which it can navigate remains unchanged. In addition, the connection between system and functionality extender modules may be flexible or articulated in a known manner, to facilitate turning corners.

[049] Functionality extender modules may also be connected to one another – e.g. in series – to increasingly extend functions of the system 132. For example, one functionality extender module may provide additional sensing capabilities for sensing structural condition of the pipeline, whereas a second functionality extender module may comprise motion detectors for determining displacement of the system to create a network map of the pipeline. Alternatively, each functionality extender module may contain further sensor connector(s).

[050] In the embodiment of Figure 1, the functionality extender module may simply be a duplicate of the system 100 with the exception that the circuitry in the functionality extender module may not need as complicated an integrated central processing unit and/or memory 154. The integrated central processing unit and/or memory is located in the housing 102 to protect it from the atmosphere within the pipe, and is in communication with the sensor(s) connected to the sensor connector(s) 104 to receive and store measurements taken thereby.

[051] With reference to Figures 3A and 3B, the end caps 108, 110 are shown. End cap 110 includes a data connection port 144 for communicating with either a functionality extender module or an external computer for downloading sensor data collected during use of the system 100. The end cap 110 further includes an encoder port 146, presently comprising a cable gland. The end caps of the functionality extender modules (not shown) are similarly configured for data communication either to/from other functionality extender modules or to the main module shown in Figure 1. To that end, the functionality extender module may comprise a data connector or encoder pin/plug in place of sensor 118, for connection to port 146 of a neighbouring functionality extender or main module.

[052] The system 100 further comprises a steering mechanism connected to the housing 102, for steering the system 100 while in the pipeline. The steering mechanism can involve powering the wheels or rollers 150 of the supports 106 such that different relative speeds of rollers can be used to turn corners and making the speeds consistent will cause the system

100 to drive straight – Figures 7A to 7C show the system 166 with supports 170 at different degrees of extension to enable the system 166 to navigate a corner. Alternatively, or in addition, where the system 100 is propelled along the pipeline by fluid in the pipeline, the steering mechanism can include one or more rudders – such as rudder 148 – for steering the system 100 using fluid pressure. Thus, some steering mechanisms may be more suitable for particular applications. In other cases, steering mechanisms are more suitable for different types of pipe materials. For example, one or more electromagnets 152 (shown in broken lines) may be provided that can be selectively activated to attract the system 100 towards the side of the pipeline closest to the respective electromagnet. To enable the system 100 to pick different branches of a pipeline etc, the electromagnets 152 may be spaced about a circumference of the housing 102 as shown.

[053] Figures 4 and 5 show pipelines or pipe networks 156, 158 through which the system can traverse to monitor the condition of the network 156, 158. To introduce the system, the networks 156, 158 include a docking station 160. The docking station 160 is a conduit (potentially also a pipe) in which the system 100 is contained out of flow of the network 156, 158. The docking station 160 can hold the system using any appropriate mechanism, such as by retention of a tether attached to the system or otherwise magnetically and/or mechanically holding the pipeline analysis system. The system can then be inserted either by driving the wheels 150 or by inserting the system into the pipeline through an existing pipeline inlet (e.g. manhole) using a pole-like mechanism or by hand. In the case of a pole the docking station is not physically connected to the network 156, 158 but is instead located at the end of the pole and is weighted to facilitate the insertion process using gravity.

[054] In some cases there will be no disruption to the product flow operation through the network 156, 158 during the process of deploying the system. The system is released from the docking station into the pipeline either through an operator request using an established communication network (which may be a wireless network, hard-wired network or other type of network) or at a pre-set time.

[055] Once the device is released from the docking station into the pipeline, it will traverse the pipeline with the aid of the pipeline product flow pushing it along or by powering the wheels 150. In a closed-loop water flow scenario, as shown in Figure 4, the device uses the same docking station for deployment and re-docking. Upon deployment, the device will traverse the entire closed-loop pipeline network 156, and re-dock itself to its original docking station after the completion of each loop.

- [056] After traversal of the network 156, the system may re-dock itself to the same docking station 160, or may be pulled thereinto by a tether.
- [057] In an open-loop water flow scenario as illustrated by the network 158 in Figure 5, the product flow does not loop back so the system does not automatically return to its original docking station. In this scenario, the system may either be powered or an automated winch-based design can be used to deploy and retrieve the system – e.g. the system is tethered to the docking station while it is traversing the pipeline and is retracted to the docking station after each deployment operation. This can be a portable setup or one-time instalment to perform day-to-day operations using the system.
- [058] Data collected during the deployment operation – i.e. while the system traverses the network 156, 158 will be transmitted back to a control station using an established communication network, which will be understood by the skilled person. The entire deployment operation and traversal of the network 156, 158 can be fully automated or be manually operated by an operator to command the system to stop at a designated section of the pipeline for enhanced data collection and visual inspection via the control station. The system may halt on request, where communication remains possible, or may halt once it detects it has reached a particular location determined as described below.
- [059] An example system for traversing networks is shown in Figure 1. A further embodiment 166 is shown in Figure 6, comprising a base housing 168 (formed by two parts sealed together in the shape of a hemisphere) with supports being numerous adaptive scissor-like spring-loaded legs 170 that extend according to the internal diameter of the pipeline in the system 166 is traversing. The scissor-like spring-loaded legs 170 extend from the base housing 168 and have a single, rotary degree of freedom.
- [060] Each support 170 has a roller 174 at its end which will meet the internal diameter wall of the pipeline 172. The self-adjusting spring-loaded legs 170 can be compressed, allowing the system 166 to conform to the internal diameter of the pipeline 172 allowing it to operate in pipelines of various diameters. The rollers 174 are provided with rotary encoders, discussed with reference to Figure 2, at the end of the spring-loaded extendable legs 170 that provide additional stability by matching rotation of the rollers 174 and connect to sensor connectors to transfer location or displacement data to the memory in the housing 168. The rotary encoders also permit measurement of the distance travelled by the base housing 168 through the pipeline 172. By determining relative rotation of each of the rollers 174, the system 166 can determine its location (if the start location is known) or its displacement from its

deployment location. As a result, the system 166 can then generate a map of the network, and halt at predetermined locations within the network.

[061] The legs 170 can also serve to detect any pit formation on the internal pipe wall due to corrosion. Spring-loaded legs of varying lengths can be removed/installed from/onto the base housing to cater to pipelines of varying internal diameter. As the rollers pass over protrusions (e.g. tree roots), or into depressions (e.g. corroded parts of the pipe) the variations in extension of the legs 170 can be used as indications of pipe corrosion, intrusions and other conditions.

[062] The base housing 168 is equipped with multiple sensors discussed above, that measure pipeline health data. The base housing 168 is designed for modularity, providing sensor connectors for various commercial-off-the-shelf sensors to be easily installed and for additional functionality extender modules to be attached. In addition, sensors measuring various parameters of interest about the pipeline flow product can also be installed on to the base housing – for example, a standard set of sensors may be fixedly attached to the housing. The sensors, and the various driven components of the system 166, are powered during deployment operations by batteries installed within the base housing 168 and will only be activated once it is deployed into the pipeline system.

[063] To navigate through pipeline networks consisting of bypass pipelines, the base housing 168 may be provided with magnets such as electromagnets 152 installed at different strategic positions. The appropriate magnets are activated when the device approaches a junction allowing the device to either turn into the bypass pipeline or continue down the main pipeline. In addition, flaps or rudders 176 installed on the base housing 168 can also be activated to guide the system 166 into making a turn into a bypass pipeline when necessary. Activation of magnets and flaps may be pre-set according to a planned route within the pipeline prior to deployment, or may be initiated upon the system 166 determining it has reached a desired location in the pipeline.

[064] Data (such as but not limited to temperature, pressure, and acoustic) collected by the various sensors installed on the base housing 168 are stored inside a micro SD memory card or other memory 154 embedded in the base housing 168.

[065] As mentioned above, at least one said sensor connected to a sensor connector of the system 100 can be an audio or acoustic sensor or detector, such as hydrophone 119 that is connected to sensor connector 104. To detect pipeline abnormalities, the acoustic data of the product flow within the pipeline recorded by the hydrophone 119 are pre-processed and fed into a machine learning algorithm. The machine learning algorithm is also trained of labelled

data and, from the labelled and unlabelled acoustic data, the machine learning algorithm learns to recognize the underlying acoustic patterns associated with a given label and thus with a given abnormality. Different types of pipe abnormalities such as metal-loss and leaks can be identified, characterised and labelled and fed into the machine learning algorithm. Since acoustic data is collected at every single point of the pipeline traversed by the system 166, any defects detected can be accurately pinpointed. Other relevant pipeline parameters such as optical images can be fused with acoustic data to provide a complete overview of the pipeline health status.

[066] Besides detecting leaks through the conventional optical means of leak detection, the machine learning method described herein may employ an artificial neural network (ANN) model that takes the collected audio data as its input and can be used to detect minute leaks and/or other abnormalities which cannot be readily be detected using optical means.

[067] With reference to Figure 8, the ANN architecture used herein may comprise a topological network with one or more, and presently two, hidden layers. For this selected ANN architecture, the number of neurons for hidden layer '1' and '2' is dependent on the size of the training dataset as determined by the formula:

$$j = \sqrt{(s+2)N} + 2\sqrt{N/(s+2)} \quad (1)$$

for hidden layer '1' and:

$$k = s\sqrt{N/(s+2)} \quad (2)$$

for hidden layer '2', where there are i features for each training sample, s represents the number of output neurons, N represents the number of training samples, j is the number of neurons in hidden layer '1' and k is the number of neurons in hidden layer '2'.

[068] This particular architecture is chosen for its ability to learn underlying patterns from a large number of distinct data samples using a comparatively small number of hidden neurons.

[069] The aim of the ANN is to minimize the error between the given labelled dataset and the values predicted by the trained model by adjusting the interconnecting weight parameters between all layers iteratively. Ample labelled training data samples are necessary for the ANN to have better insight into the underlying patterns of the training dataset as this allows the ANN to be sufficiently trained in making meaningful predictions. If the number of training data samples is too small, the ANN will not have sufficient relevant information to adequately learn these dependencies resulting in a trained model with relatively lower accuracy performance.

[070] The collected acoustic training dataset takes the form of a ' $N \times l+1$ ' matrix ' X ' as shown in Equation 3. The first column of value '1's denotes the bias, notation ' N ' denotes the

sample size of the training dataset, and notation 'l' denotes the number of features (number of data points) in each data sample. The labelled output for the training dataset is denoted by a matrix 'Y', where element 'y_{n1}' equates to value '1' and element 'y_{n2}' equates to value '0' when the nth training data is labelled as value '1' (leaking pipe) and so forth.

$$\mathbf{X} = \begin{bmatrix} 1 & x_{11} & \dots & x_{1l} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{N1} & \dots & x_{Nl} \end{bmatrix}, \quad \mathbf{Y} = \begin{bmatrix} y_{n1} & y_{n2} \\ \vdots & \vdots \\ y_{N1} & y_{N2} \end{bmatrix}$$

3

[071] From Equation 4, element 'w_{ij}¹' denotes the inter-connecting weight between the input layer and hidden layer '1', where notations 'i' and 'j' represent the 'ith' neuron in the input layer and 'jth' neuron in hidden layer '1' respectively. Likewise, element 'w_{jk}²' denotes the inter-connecting weight between hidden layer '1' and '2', where notations 'j' and 'k' represent the 'jth' neuron in hidden layer '1' and 'kth' node in hidden layer '2' respectively and so forth. The collective weight between neighboring neuron layers is denoted by matrix 'W_p', where notation 'p' denotes the weight's starting layer. These weights are randomly initialized close to zero to ensure that the neurons do not perform the same computation.

$$\mathbf{W}^1 = \begin{bmatrix} w_{11}^1 & \dots & w_{1J}^1 \\ w_{21}^1 & \dots & w_{2J}^1 \\ \vdots & \ddots & \vdots \\ w_{I1}^1 & \dots & w_{IJ}^1 \end{bmatrix}, \mathbf{W}^2 = \begin{bmatrix} w_{11}^2 & \dots & w_{1K}^2 \\ w_{21}^2 & \dots & w_{2K}^2 \\ \vdots & \ddots & \vdots \\ w_{J1}^2 & \dots & w_{JK}^2 \end{bmatrix}, \mathbf{W}^3 = \begin{bmatrix} w_{11}^3 & w_{12}^3 \\ w_{21}^3 & w_{22}^3 \\ \vdots & \vdots \\ w_{K1}^3 & w_{K2}^3 \end{bmatrix}$$

4

[072] The ANN's training algorithm may iterate between the feed-forward and the back-propagation process. In the feed-forward propagation process, the data samples are propagated through the weights of the model and the activation functions of the, generating a matrix of interim predictions at the neuron outputs. To effectively classify the non-linear relationship between a detecting pipeline leak and the collected acoustic training dataset, an activation function – e.g. a sigmoid activation function – may be applied to the weighted input at every neuron in hidden layer '1', hidden layer '2', and/or the output layer. In addition, the inputs (acoustic dataset) to the ANN may be normalized to avoid saturating the activation function of the neurons.

[073] After the completion of a forward propagation process, the back-propagation process begins. This involves calculating the error between the given labelled dataset and the values predicted by the model. Presently, the cross-entropy error (denoted by 'E') is used. Cross-

entropy is used here as it has a faster weight learning rate when the resultant cross-entropy error is large, thus any slowdown in weight optimization is avoided as the cross-entropy error minimizes with each training iteration. The cross-entropy is calculated according to equation 5:

$$E = -\frac{1}{N} \sum \sum [Y \odot \ln(OP_{op}) + (1 - Y) \odot \ln(1 - OP_{op})] \quad 5$$

where OP_{op} are the values predicted by the model.

[074] Next, partial derivatives calculations may be made throughout the ANN to determine the cross-entropy error value with respect to each preceding weight in the ANN. All calculated partial derivatives are used by the conjugate gradient descent algorithm to iteratively locate the next path to the minimal of the cross-entropy error function. This method is used as it converges the cross-entropy error function using less iterations when compared to the typical gradient descent method.

[075] The feed-forward and back propagation processes are repeated. With each iteration, the ANN's weights are automatically re-adjusted to further lower the resultant cross-entropy error between the given labelled answer and the predicted output. This is continued until convergence of the cross-entropy error function, error below a predetermined threshold or a maximum preset training iteration number is met.

[076] Given adequate and accurately labelled dataset collected from that peculiar area where the model will be implemented, a user can thus train and implement such a data-driven model to readily detect leaks for that area.

[077] Many modifications will be apparent to those skilled in the art without departing from the scope of the present invention.

[078] Throughout this specification, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.