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INTEROPERABILITY FRAMEWORK FOR SUBSEA SENSORS DATA

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Abstract

Subsea operations account for multiple sensors and systems. Monitoring and controlling offshore facilities are crucial to ensuring a safe environment for humans and sea life. Also, data post-analysis allows increased process performance for the whole installation's lifecycle. Multiple systems, lack of data model standards and non-interoperability are current challenges. Although the IFC implementation still needs improvements, its many compliant software vendors available have started granting subsea interoperability projects success. This work presents a project in progress for structure and model Subsea sensors data integrating the use of IFC. Finally, an interoperability framework is developed to guide further deployments.

Introduction

Oil and Gas (O&G) deep-water exploration is still a valuable tenure. Multiple sensors are prone to monitor offshore systems targeting managing operations (Amaechi et al., 2022; Zhang et al., 2020). The assets' integrity assessment for the identification of hazards is crucial to avoid oil leaks, and human life risks (Bucelli et al., 2018; Gauthier, 2016; Johnsrud et al., 2018). With this concern, data sensors are mainly manipulated to operate and control the facilities with fewer applications for post-analyses. Data post-processing is also relegated because of data interoperability issues (Doe et al., 2022). Diversified systems and multi-stakeholders are challenges for data integration and diffusion (Rolin et al., 2013). Based on that, O&G operators are mainly investing in processes' digitalisation and interoperability.

The virtual remote operating of industrial plants is a reality for the O&G industry; consequently, the Digital Twin trends are easily incorporated. The increased sensing technologies' availability critically boosts data acquisition (e.g., each piece of equipment can acquire one thousand readings per minute) (Brewer et al., 2019). However, processing data to deliver useful information for multiple stakeholders over gigantic organisational structures is still challenging. The O&G interoperability ecosystem is distinct from the AECOO (Architecture, Engineering, Construction, Owner Operator) (Doe et al., 2022). While AECOO has been working on disseminating IFC as a neutral and interoperable standard, the O&G industry works diffusely without consensus around ontologies that are not supported by software vendor lists (Doe et al., 2022).

Research and technological development projects are ongoing in the Brazilian O&G sector to deploy open standards for data exchange, mainly using IFC (D. L. de M. Nascimento et al., 2022a, 2022b; D. L. M. Nascimento et al., 2022). The diffusion of these initiatives is crucial to bring awareness to the whole supply chain of open standards opportunities and benefits. At the same time, the availability of multiple software IFC compliant blocks the value chain's excuse not to implement a unique ontology for each O&G Operator. This work presents the starting point of a system under development for sensors' data exchange using IFC targeting beyond the operation procedures, allowing linked syntactic data catalogues and semantic quarriable data (Doe et al., 2022).

Background

Subsea operation

The O&G subsea operation mainly involves the interconnection of the oil and gas wells to the platforms. Floating Production Storage and Offloading (FPSO) are nowadays the most used units for production and processing. The leading O&G Brazilian operator oversees more than eighteen thousand kilometres of interconnection, accounting for 1.2 MM tons of cargo capacity with more than one hundred suppliers around the globe.

In order to reduce installation costs and increase automation, a new generation of subsea units is envisaged (Zhang et al., 2020). Substantially, in this scenario, the amount of sensing technologies will increase, boosting data acquisition. Concepts of the O&G general Digital Twins (Brewer et al., 2019) and pipelines Twins (Bhowmik, 2019) are introduced to enhance big data use.

O&G Interoperability

The necessary interoperability in all industries demands a common schema and a consistent exchange method for describing and ruling multiple data sets interactions without information loss (Doe et al., 2022). Open schema and data format standards are listed in ISO 19650-4 (ISO 19650-4, 2022):

- IFC (ISO 16739-1)
- GML (ISO 19136)
- Posc/Cesar (ISO 15926)
- CAFMconnect (for built asset-orientated handover)
- COBie (for built asset-orientated equipment and impact handover)
- CFIHOS (for plant-orientated handover)
- Oscre (for various property-related transactions)

Adding to this, Due et al. (2022) emphasised that many other data models and exchange formats are applied in the O&G industry, such as:

- IEC 62714 AutomationML (Automation Markup Language)
- IEC 62264 B2MML (Business to Manufacturing Markup Language) and IEC 61512 Batch ML (Batch Markup Language)
- IEC 62541 OPC UA (Open Platform Communications, Unified Architecture)
- MIMOSA CCOM (Common Conceptual Object Model)
- MTConnect (Manufacturing standard)
- PRODML (for supporting workflows in production operations)
- IEC 62424 CAEX (Computer Aided Engineering Exchange)

Consequently, due to the vast amount of interoperability-standard-based, the O&G sector is failing inbuilt an integrated supply chain. Also, the computational software market available for exchanging multiple data models is limited and somehow inexisting. Because of that restriction, the data used by various users is minimal. The IFC is an open standard (ISO 16739-1:2018) accounting for hundreds of certified software by buildingSMART International. Finally, by incorporating IFC, the O&G industry can assimilate AECOO's lessons learned, having more human resources availability with the knowledge to conduct data-exchange projects. At the same time, more users may manipulate information, digitalising the work process and improving productivity and accuracy.

Concept and Method

R&TD project

The Open BIM project is under development joint with a Brazilian O&G Operator Company and CERTI Foundation, a Centre of Reference in Innovative Technologies. This paper presents the work for data from sensors modelled in IFC to make its information interoperable, mainly with internal stakeholders for post-processing and analysis. Operator sensors data are fed into the IFC API to be stored in ontologies. Finally, future sensors can be fed into the API upscaling data collection and use.

Collection of Information

The system requirements and sensors specifications were collected and analysed through documentation surveys, interviews, meetings, discussions, mapping process and user validation. Follow-up meetings and doubts clarifications were held frequently. Moreover, a workshop was held to validate the data sensors selection and the outcomes for users from the system pretended.

Ontology design and validation

A team of researchers performed the system design to avoid the possibility of bias. Four main layers of outcomes were targeted:

- Data dashboards to allow users to build metrics and KPIs
- Artificial intelligence data benches for predictions and routine operations
- Syntactic interoperability for a BIM catalogue with sensors' complete data modelling
- Semantic interoperability linked data for sensors' ability to query and inform

The systems' requirements and users' expectations were then verified with the support of experts from O&G Company (4 individuals) and academics with experience in research and practice in the field (4 individuals). For that, we conducted two panels of discussion with four individuals each, separating them between O&G Company and academics so that commonalities between groups could be identified. In these panels, experts were introduced to the systems' requirements and users' expectations obtained from our previous steps and were asked whether they agreed with those. In general, there was a consensus between groups regarding the items presented, and very few minor suggestions were provided to enhance clarity on the terminology. Hence, the systems' requirements and users' expectations were confirmed and utilised in our study.

The systems and artifacts

The leading systems and artifacts that will compose the proposed Subsea interoperable system (see Figure 3) are following highlighted.

Apache Kafka

Apache Kafka is a distributed real-time streaming platform composed of the three main functionalities of publishing and subscribing streams of events, storing in a durable way of streams, and processing these streams as they occur (Parisi et al., 2020).

Considering the diversity of the sensor types, the synchronisation module is critical to ensure data publication on the cloud side (Ramprasad et al., 2018). The background usage of Apache Kafka software proved to be robust, fast, adaptable, and efficient (Wang et al., 2015). Given those reasons, it is proposed to use Apache Kafka in this work.

Grafana

The Grafana tool is an open-source analytics and interactive visualisation application. It contains a complex dashboard system with various plugins developed by an extensive community, contributing to the analysis capabilities (Huynh and Nguyen-Ky, 2020). It supports multiple time-series–based data sources like InfluxDB, Prometheus, and OpenTSDB and uses SQL databases like MySQL (Chakraborty and Kundan, 2021).

The platform can export and share their dashboards in several formats like ‘csv’ to be used for analytics or delivered as a web link for visualisation (Huynh and Nguyen-Ky, 2020). This software is essential in this study for creating a dashboard to exhibit the data from the sensor database and assist in the visualisation using, for instance, heat maps representations and allows some basic calculations.

InfluxDB

Developed by InfluxData, InfluxDB is an open-source time-series database that functions as a storage of pieces of data as a point. Each point is composed of a field set and a timestamp. The attributes of each point can be indexed or unindexed (Kang and Hong, 2018).

This data storage model has advantages in CPU performance, disk space, and efficient query response. The disk usage performance and query time are more critical in sensor monitoring cases with big data. Due to its successful background usage in monitoring time-series data storage, InfluxDB was adopted as a sensor monitoring data in this work.

IFC APIs

The IFC Import API receives the project data of the sensors in IFC format and stores it in the IFC database. The IFC database comprises the catalogue (with classification data) and the instances or project database. The data are classified into class data to publish in the catalogue, and in some instances data to be stored according to their classes, properties, and, if pertinent, geometries.

The IFC export API makes the sensor's information available to end users or machines in IFC standardised format. It will be capable of exporting the IFC files or projects in several manners, for instance:

- Export an IFC from a unique sensor, with the geometry or not
- An IFC with all the sensors of equipment specified by the user
- Defining a time interval to export the data history as IfcTimeSeries objects will be possible

IFC-to-RDF converter

Several ontologies for the IFC schema were developed and generated into a final recommended ifcOWL ontology validated by buildingSMART. Also, Pauwels and Terkaj (2016) developed an IFC-to-RDF converter tool to maintain the original ICF EXPRESS schema features to the ifcOWL schema (Pauwels and Terkaj, 2016). The application converts an IFC building model to an RDF Abox graph-structured according to ifcOWL (Bonduel et al., 2018).

Graph DB

The Graph database is implemented with Ontotext GraphDB. It is a semantic web graph database tool designed to store the RDF triple-stores, which are used for efficient data storage with consistency and no loss (Hooda and Rani, 2020). One of the advantages of GraphDB is that it uses SPARQL 1.1 federated query service, distributing all the queries through several SPARQL endpoints compliant with W3C standards (D’Onofrio et al., 2017).

Sensors SPARQL Endpoint & Sensors Linked Data Endpoint

The graph database with sensors ontologies is then made available via a SPARQL endpoint. In this way, people and machines can easily query data the way they need and get the data model as ontologies.

The sensors' ontologies are made available as Linked Data endpoints so that they can be automatically fetched by machines that can access real-time measurement values directly from the Apache Kafka topics. They are stored in the sensors' real-time measurement URIs and historical data directly from the InfluxDB measurements (the tables in time-series databases are called measurements) via its API, as they are stored in the sensors' historical data URIs.

External and Internal Gateway

The PI system (Plant Information system) delivered by OSIsoft is the external gateway the Owner/Operator uses to publish the sensor data. It is a versatile and secure infrastructure software tool that manages real-time data and events (“OSIsoft | Operational Intelligence | PI System,” n.d.). It includes several software interfaces for real-time management. The PI system is widely used in the O&G sector for real-time data management and visualisation (Ram Mohan Reddi and Srivastava, 2010).

The system’s interface displays the sensor data and aids the operator by analysing and monitoring through alarms that detect instabilities in real-time. The internal system gateways listen to the sensor data from the external gateway (PI system) or directly access the unstructured published sensor measurements from the owner/operator and post it to Apache Kafka topics.

Metrics and KPIs constructor

One of the main concerns in the project management dashboards is the precise determination of a Key Performance Indicator (KPI) related to the Owner/Operator's needs and objectives (Jabraily et al., 2019). The KPI should be measurable, realistic, timely and accessible to assist the managers in making decisions and offering practical and strategic information.

The Metrics and KPIs builder will be developed in-house, allowing the user to build their metrics and KPIs or choose existing metrics to be shown in Grafana. Each KPI has a logical rule formulation capable of interpreting and exhibiting the sensor parameters data as useful information metrics. The real-time KPIs monitoring and Grafana's strategic dashboards can contribute to a better process and efficient presentation, alerting, and analysis system.

Semantic backend

The proposed development of a semantic backend aims to integrate the sensors' complete data. The semantic backend will be necessary to receive the RDF from the sensors' project data and aggregate two sources of information:

- The Apache Kafka sensor topics are stored as URIs for the sensors' real-time data measurements.
- The InfluxDB time-series data are stored as URIs from its API for the sensors' historical data measurements.

Sensor modelling in neutral formats

IFC 4.0 version features classes for 24 types of sensors, such as pressure, humidity, and temperature. However, the set of attributes of such classes is considerably limited, not carrying vital information to analyse the behaviour of sensor response, such as metrological aspects. In addition, the set of attributes cannot be edited, nor can other attributes be added in the sensor classes, as it would ultimately impair the standardisation of objects, which is precisely the main advantage and objective of modelling in neutral formats. On issues such as this, IFC has user-defined classes, which can be used to develop objects not contemplated in the current version of IFC. These are the classes used in this project to model sensors, having as attributes specific characteristics of each type of meter.

Thus, the analyst can be provided with a list of relevant information about the context of a measurement, such as its metrological characteristics, that can be useful in data analysis. Such information is also useful for developing statistical algorithms and artificial intelligence. The following sections present IFC neutral sensor modelling. It was necessary to restrict the modelling scope to metrological aspects due to the complexity of such equipment, with mechanical, electrical and instrumentation parts. Such developments can be made a posteriori since models have been developed and validated.

GrafanaO&G sensors analysed

O&G companies use several types of sensors in production processes. For the current development, five different sensors have been modelled: the pressure and temperature sensors of wet christmas trees (WCT), the topside water, gas, and oil flow sensor, the erosion probe, and the direct optical monitoring system on wires (MODA). However, building independent IFC models consists of a suboptimal solution. Ideally, models should be organised into a hierarchical structure of classes and superclass's.

Hierarchical organisation proposal for IFC models of O&G sensor data

The IFC schema consists of objects or classes of objects that can be hierarchically organised. Currently, there is no adequate definition of a sensor superclass of a higher degree of abstraction, composed of attributes common to most sensors in a productive environment. If such a class were ever developed, it would allow the development of specialised subclasses that inherit attributes from the sensor superclass and contain specific attributes for each type of sensor.

Figure 1 presents a proposed organisation for the classes of sensor objects in the IFC schema. IfcSensorType, an IFC component, would derive a superclass associated with a generic sensor (SensorTypeGeneral), with attributes common to all sensors described in the PropSetSensorGeneral property set. Subclasses specific to each sensor type can be defined at a lower hierarchical level, such as pressure and flow rate. Each subclass is assigned sets of properties (or attributes), which can be specific or used in more than one class.

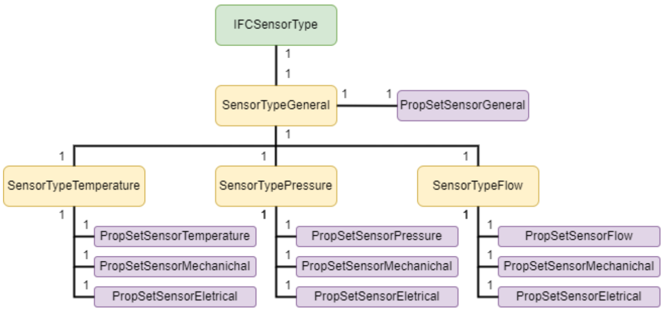

Figure 1 - Proposal for hierarchical organisation for IFC models of sensors

To build IFC models of sensor data, it is necessary to define their attributes. These attributes can be grouped to facilitate understanding. Some attributes are illustrated in Figure 2.

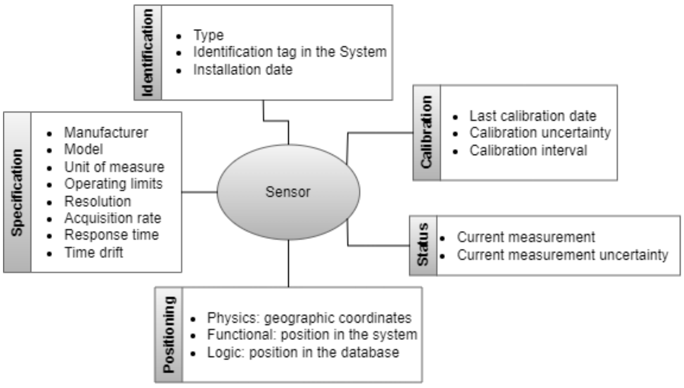

Figure 2 - Sensor object attribute groups

Each type of sensor was evaluated for the design of the sensors in IFC, and its main attributes were identified based on the specifications and experience of the design team. As mentioned above, attributes are associated with each aspect of instrumentation (mechanical design and mechanical connections with the equipment) and other elements that may be unique to each type of sensor.

In this project, emphasis was placed on the metrological aspects of the analysis.

The same methodology presented here can be used to define other attributes according to the application and required depth of neutral data models. For implementation, the Python ifcOpenShell plugin was used for ease of development and integration with other project developments. Next, the attributes identified for each evaluated sensor are presented. Each attribute constitutes metadata associated with that sensor's data.

Data from Sensors

Generic sensor

To define the attributes of the generic sensor, IFC models were developed for the sensors of interest. The sensors' attributes in common with all were separated and grouped as attributes of the generic sensor superclass. Such attributes are listed contenting IFC property name and the respective descriptions:

- Uniqueld (Exclusive sensor identifier)
- SensorManufacturer (name of sensor manufacturer company)
- SensorModel (Sensor model)
- ManufacturerId (ID for identification in the manufacturer's system)
- SerialNumber (Serial number)
- DesignLife (Sensor life declared by the manufacturer)
- ManufacturingDate (Manufacturing date)
- CalibrationDate (Last calibration date)
- CalibrationTimeInterval (Recommended calibration time interval)
- SensorWeight (Sensor mass)
- PurchaseDate (Purchase date)
- InstallationDate (Sensor installation date)
- LocationPhysical (Location of the sensor)
- StorageServer (Server where sensor measurements are stored)
- StorageServerTag (Tag that identifies the sensor on the storage server)
- RedundantSensor (Uniqueld of redundant sensors, important for assessing data quality)
- CorrelatedSensor (Uniqued of relevant correlated sensors important for data quality assessment)
- Algorithm (Description with a high level of abstraction of the algorithm used to process data)
- AcquisitionRate (Frequency of successive measurements)
- CommunicationProtocol (Communication protocol)

Wet Christmas Tree (WCT) Pressure Sensor

These sensors measure the pressure of the fluid flowing through the WCT, which helps to ensure that the system is operating within safe parameters and to detect any potential leaks or blockages. The specific IFC model of the WCT pressure sensor was conceived as composed of eight attributes, listed contenting IFC property name and the respective descriptions:

- MaxDesignWaterDepth (Maximum water column height stipulated in project)
- Accuracy (Sensor accuracy. It comprises the systematic effects and random)
- AnnualDrift (Sensor output variation over time)
- MaximumDesignPressure (Maximum project pressure)
- Resolution (Sensor resolution. Minimum variation of sensor output values)
- Repeatability (Maximum expected random variation of sensor output)
- MeasurementRange (Sensor measurement range. Values in which the sensor output is valid)

WCT Temperature Sensor

These sensors measure the temperature of the fluid flowing through the WCT, which helps to detect any changes in the fluid properties or to identify any potential issues with the system. The specific IFC model of the WCT temperature sensor was conceived as composed of eight attributes, listed contenting IFC property name and the respective descriptions:

- MaxDesignWaterDepth (Maximum water column height stipulated in project)
- Accuracy (Sensor accuracy. It comprises the systematic effects and random)
- AnnualDrift (Sensor output variation over time)
- MaximumDesignTemperature (Maximum project temperature)
- Resolution (Sensor resolution. Minimum variation of sensor output values)
- Repeatability (Maximum expected random variation of sensor output)
- MeasurementRange (Sensor measurement range. Values in which the sensor output is valid)

Flow sensor

These sensors measure the rate at which the fluid flows through the WCT, which helps ensure that the system is operating at optimal efficiency and detect any potential issues with the flow rate. The topside flow sensor can measure oil, gas, water and even multiphase. For its modelling, fourteen attributes were identified, listed contenting IFC property name and the respective descriptions:

- FlowComposition (Fluid composition involved in the process: oil, water, gas, or multi-phase)

- Accuracy (Sensor accuracy. Comprises the systematic effects and random, but without considering the error of zero)
- AnnualDrift (Sensor output variation with time)
- TemperatureDrift (Sensor output ratio with the temperature)
- PressureDrift (Sensor output variation with pressure
- NominalFlow (Nominal sensor flow)
- ZeroStability (Zero stability of the sensor)
- Resolution (Sensor resolution. Minimum variation of sensor output values)
- ·Repeatability (Maximum expected random variation of sensor output)
- MeasurementRange (Sensor measurement range. Interval values where the sensor output is valid)
- ProcessPressureRange (Maximum and minimum process pressure)
- ProcessTemperatureRange (Maximum and minimum process temperature)
- AmbientPressureRange (Maximum and minimum)
- AmbientTemperatureRange (Maximum and minimum ambient temperature)

Erosion probe

These sensors measure and monitor the rate of erosion on subsea structures and pipelines. It typically consists of a sensor that is placed near the structure or pipeline and is used to measure its thickness over time. This information can then be used to determine the rate of erosion and can also be used to predict future erosion and plan for maintenance or repairs. The IFC model for the erosion probe has thirteen attributes, listed contenting IFC property name and the respective descriptions:

- DesignPressure (Maximum operating pressure)
- HydrostaticTestPressure (Project pressure x 1.5)
- HyperbaricTestPressure (Maximum pressure value that the sensor can operate)
- ProbeDiameter (Probe diameter)
- ProbeLength (Probe length)
- SensingElement (Element type material loss sensor)
- ElementMaterial (detection element material)
- ElementThickness (Reference thickness for the detection element)
- ElementLife (Loss of maximum material)
- Resolution (Sensor resolution. Minimum variation of sensor)
- MaxDesignWaterDepth (Maximum water column height)
- TemperatureRange (Project temperature operating range)
- AmbientOperatingTemperatureRange (Operating ambient temperature range)

MODA System

The MODA system (Monitoring based on Optical fibre attached Directly to Armor wires) uses optical sensors and strain gauges based on Fiber Bragg Grating (FBG) technology attached to each wire of the outer tensile armour. These sensors make it possible to detect broken wires and events associated with wire ruptures. The MODA system was designed to focus on seven specific attributes, listed contenting IFC property names and the respective descriptions:

- QuantityFBGMeasurement (Amount of FBG sensors installed)
- FBGsTemperatureMeasurement (Table with FBG sensor identifiers for compensation temperature)
- QuantityWiresExternal (Number of wires in the armour external)
- QuantityWiresInternal (Number of wires in the armour internal)
- PercentageWiresRequired (Percentage of necessary wires for safe operation)
- ReferenceMeasurements (Measurements of the initial period used as reference)
- Model (How broken wires are modelled and identified)

System architecture and ontology

The diagram in Figure 3 summarises the architecture and ontology of the interoperability for Subsea sensors data system in two parts. At the top of the diagram, the values sent from the sensors are published via PI and through gateways, initially using Node-RED. The system keeps listening to these sensors. Each sensor is published individually in the event storage system (Apache Kafka). Within Kafka, some topics will be offered for stream processing. In this case, signal processing is optional

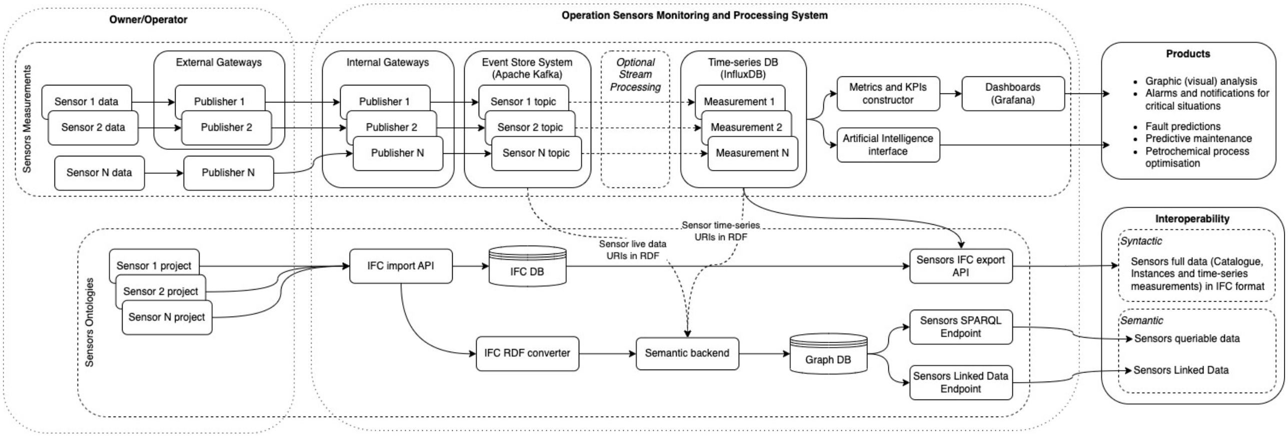

Figure 3: Interoperability system for Subsea sensors data

because, in some cases, one may want to store the raw data, and in others, it will be necessary processing, as in cases of noise. For example, the signal from the flow sensor, which is 3000 meter deep, may suffer from the noise effect. Raw or processed data is stored in a time series database (InfluxDB), where extensive data is stored since some sensors send hundreds of data per second for long periods.

From this data can apply metrics and KPIs constructors as the main final product of the Dashboards (Grafana). These can be generated in addition to visual information, alarms and notifications involving critical events. Another possible output is a machine-learning application, which among several possibilities, can provide a prediction of failures and information for predictive maintenance and optimisation of the petrochemical process. At the bottom of the system's design, the interoperability happens through storing projects in neutral standards, their semantic enrichment and availability for external systems such as 3D viewers and analysis software. It starts with the structuring of the ontologies of the sensors in IFC. Once you have this data, you can import the design of the sensors in IFC via API, providing access to enriched information. First, the sensor data is stored in the IFC (IFC DB) database; in parallel, the API converts IFC into RDF format. Thus, organising the information in a syntactic (IFC DB) and semantic (IFC RDF Converter). The semantic backend receives semantic information from the sensors making it possible to enrich knowledge progressively.

As stated earlier, Kafka organises the information into topics. Each published topic contains URIs, which can be aggregated into the sensor design information. The Time Series Database also has URIs peered to measurements. The sensor design can receive real-time data and information from where the historical data is stored by saving these URIs in a graph database (Grapho DB). Thus, through SPARQL Endpoints and Linked Data Endpoints, users can consult the sensors and access URIs that refer to the sensor's real-time data, history and everything related.

Conclusions

In the context of metrics and the construction of key performance indicators (KPIs), end-user needs involve identifying the specific data and information that is important to users and how they want to access and analyse it. One way to meet end-user metrics and KPIs needs is through dashboards such as those built using Grafana. These dashboards allow users to view and interact with their data visually and intuitively easily. At the same time, AI can help automate and optimise the collection and analysing of data, making it even more accessible and valuable to end users.

The system offers multiple options for accessing information to the end user. Sensor design syntactic and semantic data: Export 3D IFC models with sensor data according to customisable scope. The exported IFC 3D model with the sensor design and their measurements can be viewed by various 3D viewers. In addition to providing an interface for semantic queries SPARQL and Linked Data.

Interoperability specifications refer to guidelines and standards that ensure that sensors can effectively communicate and share data with other systems and software that also use IFC. These specifications cover a wide range of technical details, including the format of data being exchanged, the protocols used for communication, and the methods for handling errors and exceptions. Further research will target the system deployment and continuous O&G sensors' data modelling extending the IFC standard.

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