HiPRWind

High Power, high Reliability, Off-shore Wind Technology

PROJECT DELIVERABLE REPORT

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Database for data collection and communication system description

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Abstract

The initial objective of the deliverable was to summarize the work carried out in Task 3.3: Communication with the test platform, and T3.4: Data collection and assessment of the floating platform. It was expected to deliver D3.3 by the end of the project with the description of the communications system design and the database –sizing, access to the information, description of the information available…-

During the second and third periods of the project, the work was focused on the design of the communication system and the database, in close cooperation with WP6 Condition and structural health monitoring. After several discussions to understand the requirements and different communication protocols of all the monitoring systems, it was decided the architecture design of the communication system and the database.

The report summarized the communication system and database requirements and the considerations that should be taken into account for the practical implementation of both, the SHM systems and the communications system, based on TECNALIA's DAS system.

The deliverable was scheduled for the last month of the project. Although the project has been suspended and the communication system and database have not been developed, there are interesting considerations related to sensor monitoring systems that could applicable to the offshore wind sector. Thus, a DRAFT version summarizing design considerations, sizing and even some reference prices has been produced.

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1 Purpose and scope

The main aim of this document is to define a common methodology and deployment strategy for the different monitoring systems to be installed in the HiPRWind floating offshore wind turbine. It was decided to follow V-Model methodology for the instrumentation and control deployment.

The initial objective of the deliverable was to summarize the work carried out in Task 3.3: Communication with the test platform, and T3.4: Data collection and assessment of the floating platform. It was expected to deliver D3.3 by the end of the project with the description of the communications system design and the database –sizing, access to the information, description of the information available…-

During the second and third periods of the project, the work was focused on the design of the communication system and the database, in close cooperation with WP6 Condition and structural health monitoring. After several discussions to understand the requirements and different communication protocols of all the monitoring systems developed in the framework of WP6, it was decided the architecture design of the communication system and the database.

The report summarized the communication system and database requirements and the consideration that should be taken into account for the practical implementation of both, the SHM systems and the communications system, in order to ensure the proper operation of the wind turbine and guarantee the data collection for the dynamic behaviour of the floating prototype. In this sense there was also a close collaboration to WP2, for the installation and commissioning of the sensors and communications devices for each SHM system.

Communication system will be based and designed around TECNALIA's DAS system. A description of the features of this system is included in ANNEX I.

2 Access system for the floating structure

The methodology being used for the instrument and control deployment is based on the V-Model for development processes. The steps of the methodology are as follows:

1. Operational requirements are defined in order to provide an architecture overview and system design (this document). Functional requirements of the common communication bus, data rates, and databases must be also provided.
2. After agreement on phase 1), using information provided by single partners about sensors and DAQs, a detailed architecture with cable positioning, schemas and specific sensor deployment specification is designed.
3. Following the agreement on phase 2), implementation, installation, operation and maintenance specification for each monitoring subsystem must be provided.
   NOTE: This phase requires a good cooperation with floater and wind turbine manufacturers in order to fit the SHM system installation in the general fabrication schedule. An important topic related to installation and maintenance is the protection system which has not been defined so far. Tubes, sensor protections, watertight closings are supposed to be defined by WP6 partners. Responsibilities in O&M must be defined.
4. Commissioning of materials, in-factory sensor installation (if needed) and industrial PC/DAQ implementation.
5. In lab environment and/or in harbour real environment, unitary tests of cables, sensors and DAQs for verification are performed.
   NOTE: Harbour SHM system tests must be well-defined in advance to fit this task in the general assembly schedule in Aviles port. Delays in this task cannot be afforded due to the fact that expensive marine vessels will be waiting for the platform. Depending on marine operations contracted, the platform will be moored in port for 7-10 days for stability and ballast system tests (Spanish authority's requirement). Onshore and offshore commissioning must be defined in advance in order to investigate what is the best point in fabrication/installation schedule to carry out the tests.
6. Sequentially, subsystems integration, verification and validation will be performed.
7. Finally, full system integration with onshore SCADAs and databases is performed.

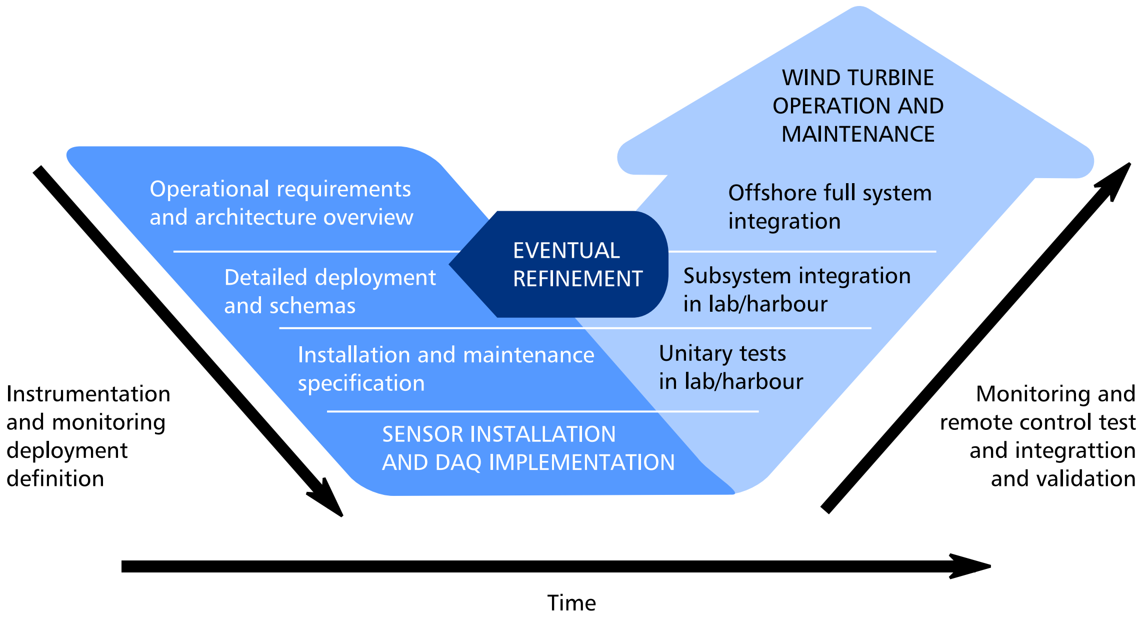

Figure 1. V-Model

Along the different phases feedback loops among them could be done for refinement as measures for eventualities. However, due the nature of the project, all relevant aspects should be always provided before each phase is started (prerequisites) in order to avoid feedback or further refinement loops.

3 Operational and safety requirements overview

The following sections are focused on providing a common view of the general suggested feasible architecture which satisfies the following operational and safety requirements:

1. A redundant remote operating channel must be provided to fulfil safety requirements for the BIMEP area and permanent control of wind turbine by Acciona and/or BIMEP.
2. Main operation channel should be separated from the protocols used by the remote monitoring systems. Ideally the separation can be done from physical interfaces or at least from a logical point of view (protocols sharing physical layer).
3. Due to installation, operational and maintenance costs, heterogeneity, technological uncertainty, dispersion and configuration complexity should be reduced as much as possible.

   NOTE: As it has been discussed in other meetings and in order to fulfil the operational and safety requirements, commercial sensors are preferred. The project aim is to understand the dynamic and structural behaviour of the platform in order to acquire the knowledge and skills for future developments. Monitoring task is the one which let us to understand and validate the simulation tools. As a research project, installation of more sensors can be foreseen during operation phase. These sensors would satisfy partial objectives of the project such as experimental sensors validations, sensors behaviour in offshore environments and so on.

4 Onshore-offshore communication architecture overview

The following diagram is the architectural draft overview. It shows the different channels and systems involved in the communication between the floating wind turbine and the on-shore substation. So far, a central SCADA has not been specified yet (neither has its possible location), but for configuration and complexity reduction three different channels have been defined:

4. Operating channel; enables remote control of the wind turbine. Protocols involved: MODBUS over TCP/IP using optical fibre.
5. Monitoring channel: user channel for time-series sample uploading into the onshore time-series data-base (mainly unidirectional dataflow). Protocols involved: OPC DA/HAD over TCP/IP using optical fibre.
6. Redundant operating channel: backup radio link between onshore Substation/Center and floating wind turbine. Protocols: To be defined.

Onshore substation monitoring: data traffic will be relayed to HiprWind time-serie database.

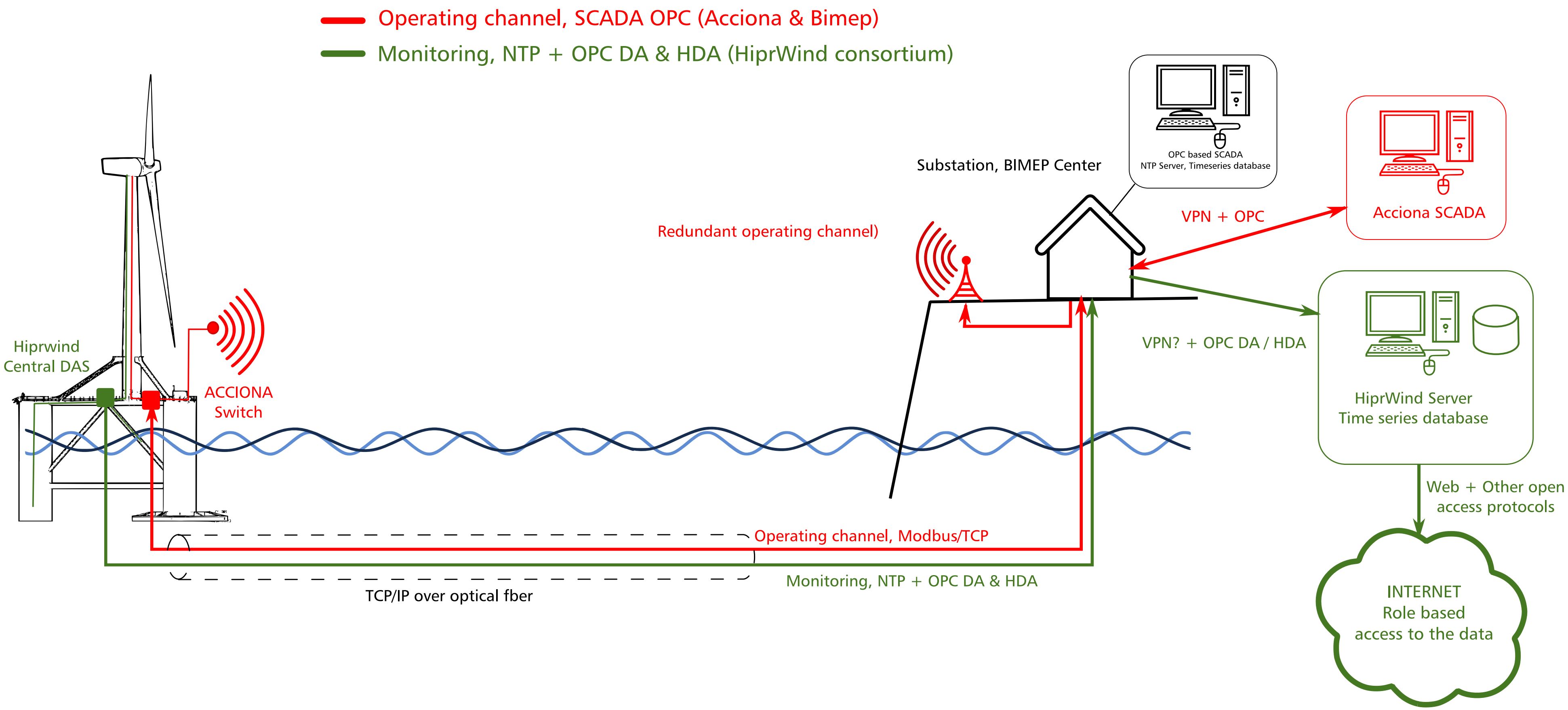

Figure 2. Architecture overview of onshore-offshore communication

5 Wind turbine instrumentation and network deployment overview

The following diagram describes the network deployment overview of the different devices and subsystems that will be installed in the floating wind turbine. The draft diagram was designed based on documents and information provided by the partners.

In the diagram, logical connections between devices and Central DAS are provided as well. These logical connections should be refined with detailed information of the different devices and protocols that will be used by the partners (see section 6).

One of the main requirements for the wind-turbine network design is that communication between devices located at Plant and Nacelle must use TCP/IP protocols over the single optical fiber. This requirement will simplify installation of cables, system integration, configuration and maintenance (R2.1 in section 6).

Logical deployment diagram of Controllers, DAQ subsystems and DAS subsystem

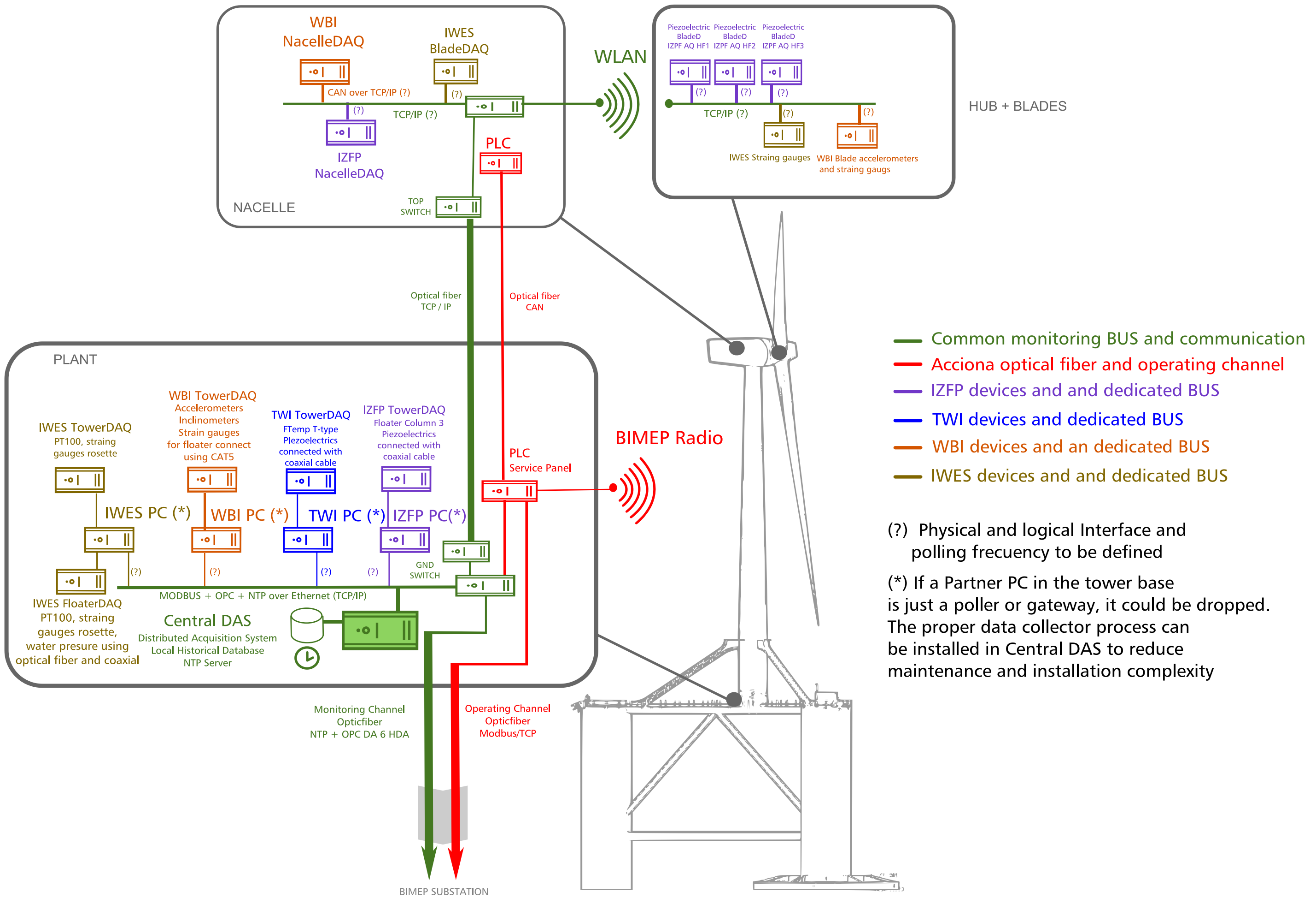

Figure 3. Deployment overview of wind turbine internal and networking

6 Requirements

The following list includes the requirements which must be taken in consideration by the consortium in order to refine the actual "Onshore-offshore communication overview" diagram and the "Wind turbine instrumentation and network deployment overview". After general agreement and clarifications, a further detailed design will be specified.

Note: RX.X items are requirements to be fulfilled by the system. MUST requirements are mandatory. However, SHOULD requirements are optional or "nice to have" features. QX.X items are requests for clarification that, after specification, can be later transformed in requirement during system design. Unless specified, any reference to the wind mill will include the floater.

6.1 Onshore-Offshore communication and central database

Requirements

- R1.1 Central DAS MUST synchronize its internal clock with the onshore substation/SCADA using NTP.
- R1.2 Operating channels (radio and control protocol over fiber) MUST be separated from common monitoring bus for data-transfer, in order to ensure that the wind turbine can be controlled independently.
- R1.3 Operating channels MUST be separated at physical level when possible.
- R.1.4 HiprWind Server Database implementation MUST be oriented to time-series storage. Secure connection and role-based access should be provided for safe data access.
- R.1.5 HiprWind Server's Database MUST store values with a predefined timestamp and value-resolution (e.g., doubles with ms) and a maximal frequency transfer-rate should be guaranteed (e.g., 10min period-1Khz). Data-transfer delay is permitted (no real-time specification).
- R.1.7 In case of some failures there SHOULD be a control device which activates and changes the storage settings. In these cases, time series 10 minutes before and after the failure might be needed.
- R.1.8 HiprWind Server's Database implementation SHOULD classify the tags based on asset hierarchy (signals from floater, blades, operational data, etc).
- R.1.9 In HiprWind Server's Database, massive volume data writing/reading SHOULD be guaranteed. Easy configuration for new tag (signal/variable) should be provided for system scalability.
- R.1.10 User-friendly access and open protocols capabilities MUST be provided by HiprWind's Server: time interval-based queries and visualization, signal comparison, CSV export, HDF5, etc.

Requests for clarification

- Q.1.2 Failure events should be defined for the different SHM systems and their associated sensors.

6.2 Floating wind turbine: internal communication and devices

Requirements

- R2.1 TCP/IP protocols MUST be used as main transmission mechanism between the partner PCs and Plant/Nacelle monitoring communications.
- R2.1.1 Communication between devices located at Plant and Nacelle MUST use the single optical fiber crossing the tower.
- R2.1.2 PowerLAN or similar cable based protocol MUST be avoided between Hub and Nacelle.
- R2.1.3 WLAN MUST be used as physical transmission protocol between Hub and Nacelle.
- R2.2 Logical isolation of control and monitoring network SHOULD be ensured, with the exception of the data interchange points (as defined in the previous drawings) for operational data sharing.
- R2.3 Due to operational reasons, redundant wireless protocols in complementary monitoring subsystems at Nacelle and Hub should be avoided.
- R2.4 Similar to R1.1, NTP protocol MUST be used for clock synchronization between different subsystems (between PCs, DAQs and DAS).
- R2.5 Information transfer between a partner PC and the Central DAS MUST be performed using following approaches: in real-time (actual value triggering/pooler) or/and accumulated time-series during a time-interval (buffer-based).
    - R2.5.1 MODBUS and/or OPC DA MUST be used for transmission of low-frequency measurements between partner PCs and Central DAS.
    - R2.5.2 To avoid bandwidth overload, in case of high-frequency measurements, measurement transfer between a partner PC and the Central DAS MUST be transferred in a buffer-based basis with periodically or event-fired/triggered.
    - R2.5.3 OPC HAD and/or FTP using open file formats MUST be used for transmission of high-frequency measurements between partner PCs and HiprWind Central DAS.
    - R2.5.4 Time-series transfer of high-frequency measurements between partner PC and the Central DAS SHOULD be compressed.
- R2.6 Central DAS MUST synchronize all incoming data from partner PCs. Time series MUST be stored in local cache for later transmission.
- R2.7 Local cache located in Central DAS MUST store data for a convenient time-interval for later transmission to on-shore database (no data-loss).
- R2.8 Simple DAQ pooler-processes for low frequency data SHOULD be installed in Central DAS.
- R2.9 Similar to the transport sector: moving parts in devices SHOULD be avoided. Fan-based electronic devices or conventional hard-disks are not allowed. Electronic devices should be proven to be functional under moving environment (using shakers or providing manufacturer specification).

- R2.10 All electronic devices MUST fulfill industrial grade maturity (extended temperature and humidity range).
- R2.11 All electronics devices SHOULD have outdoor enclosure protection.
- R2.12 All devices located outside tower-base MUST specify the IP protection level.
- R2.13 The use of optical buses SHOULD be prioritized instead of electrical cables.
- R2.14 Functionality of the sensing subsystems SHOULD be ensured under failure of a discrete sensor.
- R2.15 All systems and subsystems MUST be protected against overvoltage and lightning.

Requests for clarification

- Q2.1 Definition of information transfer scheme between data acquisition PC/subsystems and Central DAS must be specified.
- Q2.2 MUST requirement for protocols between Central DAS and PC devices must be ratified. Suggested: OPC DA/HAD, FTP and MODBUS.

6.3 Sensor and database considerations

- R.3.1 Tracking of intended monitored physical parameters MUST be insured by means of a table (T.S1). This table will identify monitored physical parameter describing number of channels reading the parameter, sensor used in each channel, acquisition subsystem hosting these sensors, and partner responsible of the sensor.
  A univocal identifier tag (IT.S1) MUST be given to the each single sensor to enable tracking along its life cycle.
- R.3.2 Another table (T.A1), MUST identify all the acquisition subsystems, describing the hardware elements building the subsystem and the logical channels reading the physical parameter.
  A univocal identifier tag (IT.A1) MUST be given to the each acquisition subsystem to enable tracking along its life cycle.
  A univocal identifier tag (IT1.A2) MUST be given to the each channel of each one of the acquisition subsystems to enable tracking along its life cycle.
  A univocal identifier tag (IT1.A3) MUST be given to the each hardware element of each one of the acquisition subsystems to enable tracking along its life cycle.
- R.3.3 Redundancies among subsystems and sensors monitoring the same physical parameter MUST be identified.
  A table (T.S2) referencing elements of T.S1 by its identifier tag (IT.S1) reading the same physical parameters in locations with similar behavior will be generated.
  A table (T.A2) referencing subsystems and channels of T.A1 by its identifier tag (IT.A1) and (IT.A2) acquiring the same physical parameters in locations with similar behavior will be generated.
- R.3.4 A database summarizing the full information of each one of the sensors MUST be insured by means of a table (T.S3) referencing elements of T.S1 by its identifier tag

(IT.S1). The table will contain, at least, the univocal identifier tag of the sensor, subsystem hosting the sensor (IT.A1), sensor channel in the subsystem (IT.A2), partner responsible, detailed location in the wind mill, inner or outer placement of the sensor, resolution of the sensor, sampling frequency, thermal characteristics, mechanical characteristics, electrical characteristics, electrical physical interface and connections with (IT.A3), network protocol, network logical interface, cabling characteristics, manufacturer reference of the sensor and associated brochure and/or specification data sheet.

- R3.5 A database summarizing the full installation procedure of each one of the sensors MUST be insured by means of a table (T.S4) referencing elements of T.S1 by its identifier tag (IT.S1). This installation procedure will identify and fully describe the steps to be followed by the installation responsible and the materials and tools required for the installation.
- R3.6 A database summarizing the maintenance procedure of each one of the sensors MUST be insured by means of a table (T.S5) referencing elements of T.S1 by its identifier tag (IT.S1). This maintenance procedure will identify and fully describe the steps to be followed by the maintenance responsible and the materials and tools required in maintenance operations.
- R3.7 A database summarizing the protection scheme of each one of the sensors MUST be insured by means of a table (T.S6) referencing elements of T.S1 by its identifier tag (IT.S1). This protection scheme will identify and fully describe the security elements and subsystems protecting the sensor against expected unexpected endogenous and exogenous failure events and the materials and tools required by the protective actions.
- R3.8 A database summarizing contingency plans under failure or unexpected event of each one of the sensors MUST be insured by means of a table (T.S7) referencing elements of T.S1 by its identifier tag (IT.S1). These contingency plans will identify and fully describe the actions and measures to be taken in order to restore, when possible, the sensor to a fully operational state. It will address also recommendations for possibility of continuous operation of the faulty sensor and/or its replacement along with the materials and tools required by the contingency plan.
- R3.9 A database summarizing scheduling of sensor installation according to floater, tower and blades fabrication schedule and clear explanation of possibilities for sensor installation (during or after the manufacturing/welding) MUST be insured by means of a table (T.S8) referencing elements of T.S1 by its identifier tag (IT.S1). This schedule will define the timeframe for installation of the sensor and the materials and tools required for the installation along with the partners involved in the installation procedure.
- R3.10 A database summarizing the full information of each one of the acquisition subsystems MUST be insured by means of a table (T.A3) referencing elements of T.A1 by its identifier tag (IT.A1). The table will contain, at least, the univocal identifier tag of the subsystem (IT.A1), partner responsible, detailed location in the wind mill, thermal characteristics, mechanical characteristics, electrical characteristics, electrical physical

interface and connections with the monitoring system and (DAS) and sensors (IT.S1), network protocol, network logical interface, cabling characteristics, estimative volume of data acquired and sent to the DAS, latency and format of the data sent to the DAS, manufacturer reference of the hardware elements of the subsystem (IT.A3) and associated brochure and/or specification data sheet.

- R3.11 A database summarizing the full installation procedure of each one of acquisition subsystems MUST be insured by means of a table (T.A4) referencing elements of T.A1 by its identifier tag (IT.A1). These installation procedures will identify and fully describe the steps to be followed by the installation responsible and the materials and tools required for the installation.
- R3.12 A database summarizing the maintenance procedure of each one of the acquisition subsystems MUST be insured by means of a table (T.A5) referencing elements of T.A1 by its identifier tag (IT.A1). This maintenance procedure will identify and fully describe the steps to be followed by the maintenance responsible and the materials and tools required in maintenance operations.
- R3.13 A database summarizing the protection scheme of each one of the acquisition subsystems MUST be insured by means of a table (T.A6) referencing elements of T.A1 by its identifier tag (IT.A1). This protection scheme will identify and fully describe the security elements and subsystems protecting the acquisition subsystems against expected and unexpected endogenous and exogenous failure events and the materials and tools required by the protective actions.
- R3.14 A database summarizing contingency plans under failure or unexpected event of each one of the acquisition subsystems MUST be insured by means of a table (T.A7) referencing elements of T.A1 by its identifier tag (IT.A1). These contingency plans will identify and fully describe the actions and measures to be taken in order to restore, when possible, the acquisition subsystem to a fully operational state. It will address also recommendations for possibility of continuous operation of the faulty subsystem and/or its replacement along with the materials and tools required by the contingency plan.
- R3.15 A database summarizing scheduling of acquisition subsystem installation according to floater, tower and blades fabrication schedule and clear explanation of possibilities for sensor installation (during or after the manufacturing/welding) MUST be insured by means of a table (T.A8) referencing elements of T.A1 by its identifier tag (IT.A1). This schedule will define the timeframe for installation of the sensor and the materials and tools required for the installation along with the partners involved in the installation procedure.
- R3.16 A database summarizing a test plan for the sensors, data acquisition subsystems and communication subsystems MUST be insured by means of a table (T.A9) referencing elements of T.S1 and T.A1 by its identifier tag (IT.S1) and (IT.A1). These test plans will define the operations and procedures to be followed tu verify and validate the fully functionality of the sensors and data acquisition subsystems, and the materials and tools required for the testing.

- R3.17 Definition of the mooring lines monitoring and connection to the WBI measurement system MUST be identified.
- R3.18 Definition of wave height monitoring and connection to the WP6 measurement system MUST be defined and identified.
- R3.19 WBI SHOULD clarify when any sensor is damaged, if they can identify it easily and fix it remotely, or what seems more logical, an estimative of its information using sensor in its proximity, it is used instead.
- R3.20 Internet connection MUST be insured for remote monitoring and operation of sensor by WBI.
- R3.21 Only one of the lower braces has been proposed to be monitored with strain gauges. Looking at the experience with strain gauges offshore, it SHOULD be reasonable to have another brace monitored. To be further discussed and agreed.
- R3.22 A meeting with RAVE project responsible SHOULD be held to share the lessons learnt and get advice for the installation and deployment of HiPRwind.
- R3.23 After meeting with professors of Cadiz University it has been stated that heat from welding will not affect strain gauges. Welding procedures will he held far enough (>1.5m) of the strain gauges, heat will be dissipated.
- R3.24 Welding tests SHOULD be done in order to ensure that welding electrical currents do not affect strain gauges installed in the structure. Further discussion and an agreement needs to be done.
- R3.25 An analysis of cabling protective pipes SHOULD be done upon completion of table T.S1 to study wiring protection.
- R3.26 Epoxy SHOULD be used for strain gauges protection instead of cyanocrylate.
- R3.27 Strain gauges MUST be avoided in outer faces of the lower braces. The gauges should be placed in the inner faces and WP6 leader should address protective actions for the gauges as its replacement will be complicated
- R3.28 Redundancies in sensor instrumentation among different subsystems SHOULD be avoided.
- R3.29 Proper sealing of sensors against water and moisture MUST be considered. Some areas of the platform will have water condensation such as braces and some dry compartments in the floaters. Protection of sensor and transmission cables against this phenomenon (almost uncontrolled) must be guaranteed.
- R3.29.1 For Strain Gauges, protection with neoprene and epoxy SHOULD be used.
- R3.29.2 For encapsulated sensors, IP67 case MUST be used. Strain gauges MUST have IP67 protection in the outer upper braces. It is not possible inner installation due to access difficulties.
- R3.30 Proper sealing of electronics equipment and communication equipment against water and moisture should be considered. IP67 MUST be used.
- R3.31 The rotation range of the nacelle MUST be analyzed when designing the dimensions of the connecting cables.
- R3.32 Versatile calibration of the sensors MUST be provided.

- R3.33 Digital post-processing in the acquisition system SHOULD be the desirable option.
- R3.34 Digital transmission MUST be considered rather than analog transmission of the measurements across long distances.

Requests for clarification

- Q3.1 Further information of the used sensors by all the partners would be desirable in order to define SHM system O&M protocol by WP3 partners.
- Q3.2 Analog to digital conversion equipment placement for electronic sensors must be revised: In order to ensure proper operation of the monitoring systems, it is desirable to place conversion and/or amplification modules the closest possible to the sensor.

7 Sizing of the Central Time Series Database

The aim of this section is to analyse the different approaches and available technologies that can be used to implement the central time series database for the HiprWind project. Furthermore, it proposes a database implementation that satisfies the requirements of the project. This document is based on the requirements collected in previous sections.

7.1 Main Technical requirements for the central database

Number of tags (signals to be stores): 300

Maximum sampling rate of signals: 10 KHz

Mean sampling rate of the signals: 1Hz

Data time availability: 3 months of data of high frequency.

7.2 Comparison of available database technologies for time series storage

7.2.1 PI System by OSIsoft

OSIsoft's PI System is the leading technology for operational time series databases in critical sectors like oil&gas, energy and industry. OSIsoft provides multiple connectors, interfaces and adapters to collect and visualize data using most common communication protocols. For instance, it provides direct gateways for data visualization in Excel and history export using OPC for analysis in Matlab or similar tool. KPIs and notification can be configured as wells.

PROS: PI's most important features of PI are Configurable data compression data capability, scalability, availability and performance. Due to its wide deployment in the industry, it is a well proven technology with very high reputation. It performs a user-role based control access to data with an asset-centred data structure for time series classification. All these features converts PI as the natural choice for the HiprWind project. Furthermore, Acciona and Tecnalia have experience managing PI Systems.

CONS: the price and maintenance license costs are high compared to common relational databases or similar open source solutions that are usually free of charge. Furthermore, OSIsoft's business model is focused on providing solutions to energy operators instead of provided time series storage for other purposes like research activities (this point should be clarified with OSIsoft).

7.2.2 Proficy Historian by GE

Proficy Historian is another widely used technological solution from General Electric. It is being deployed for several sectors like energy and industry. Similar to PI System, it supports the most common protocols for data transmission to the database and the later history access. It supports dataloss-free compression, but unfortunately the finest timestamp resolution is one millisecond. This implies that high-frequency data frames cannot be stored in the database. Data and tag scalability is ensured and licensing is more affordable compared to PI.

7.2.3 OpenTSDB

OpenTSDB is the main open source solution for timeseries storing mechanism. It is based on the HBase, a widely used NoSQL Open source databases server. The query mechanism for historical data and the insertion of data is based on REST web services. Usually, to dump incoming data to the server new protocol gateways should be implemented. The finest timestamp resolution reaches is one single millisecond, being impossible to store timeframes with higher frequencies than 1 kHz. The solution is designed focused on IT asset monitoring but it can be used as general time series storing mechanism. The relying HBase technology is a well proven technology, but OpenTSDB is quite new on the open source market without relevant references in industrial intensive applications.

7.2.4 AspenTECH InfoPlus

AspenTECH is a common technology for oil&gas and chemical processes. Unfortunately at the moment the technical specifications are only visible for registered users under AspenTECH's official support program.

7.2.5 Specific implementation using general NoSQL or RDBMS system

Another solution that can be implemented for the HiprWind project is to use a reliable relational database server (like MySQL or Postgres) and to tune it properly for intensive time-series data storing. This approach is widely used in research projects but it seems to be a "reinventing the wheel approach".

One advantage is the possibility to choose an open source database server to avoid license fees. The possibility to tune up the system for the specific application without restrictions is another benefit, but unfortunately it usually needs considerable implementation efforts to ensure the necessary requirements as scalability and data throughput. The AlphaVentus project used this approach to create a project-Specific data warehouse.

In the next page a brief comparison of the mentioned technologies is summarized.

Comparison of database technologies

	Timestamp resolution	Throughput	Scalability	Access control	Asset hierachy	Supported protocols and file formats	Price	Comments
OSIsoft's PI	**round 100Khz** = 15.26 microsec	**Ensured**. Up to 1million events / second using buil-in buffering system and multi-server systems	**Yes**. High scalability features with built-in distributed architecture, up to millions of tags and stored points and events.	**Yes**. User-Role based access control to stored data	**Yes**. Asset Hierarchy is supported for tag classification	**Several**. OPC, Modbus, SQL, csv…	60.000$ for a 5000 Tag Server, + per user licenses and protocol plug-ins (round 150.000$)	Technology standard in the energy industry as timeseries database. High reliability and official support
GE Proficy Historian	**1kHz** = 1 millisencond	**Ensured**. Up to 1million events / second using buil-in buffering system	**Yes**. High scalability features with built-in distributed architecture, up to millions of tags, stored points, events...	**Yes**. User-Role based access control to stored data	**Yes**. Asset Hierarchy is supported for tag classification	**Several**. OPC, Modbus, SQL, csv…	N/A. Probably same license schema as PI but cheaper price. Free for 25 tags with unlimited points	Very similar to PI, with less scalability features. Probably more cheaper
OpenTSDB	**1kHz** = 1 millisencond	**Ensured** using distributed DB and load balancing mechanisms. A TSD can handle 2000 data points per second per core on an dual-core Intel Xeon CPU from 2006. More modern CPUs will need more throughput.	**Yes**. Distributed storage can be configured	**Must be implemented**. REST requests should be filtered in order to provide security and access control to data	**Must be implemented**. Asset hierarchy-tree should be implemented usig tag name convention (not diffcult)	**Only REST service** for query/insert of data. Gateways for industrial or propietary protocols must be implemented	Free / No fees	Based on Hbase, this TSDB is focused on IT monitoring. Scalability and throughput is ensured but with 1Khz maximal timestamp resolution. Customization for HiprWind would be needed
AspenTECH InfoPlus.21						**Several**. Mainly OPC and export to Excel, but also SQL, web services	N/A	Compiting solution to OSIsoft in the oil&gas sector
Specific implementation for HiprWind using common NoSQL or RDBMS technologies	**Unlimited**. Depending on the performed implementation	**Ensured.** Similar to PI or Proficy if buffer system is configured in the relaying DB technlology	**Yes**. In common DBs, distributed storage can be configured	**Yes**, but for some technologies like RDBMS. User-Role based access control to stored data	**Must be implemented**. Asset hierarchy-tree should be implemented usig tag name convention	**Only via SQL API or REST service** for query/insert of data. Gateways for industrial or propietary protocols must be implemented	Free / No fees	Most flexible solution butit requires implementation efforts

7.3 Server Sizing

The following dimension estimation is used for hardware selection for the server, using a spreadsheet provided by OSIsoft.

Expected Point Count	**300**	points
PI Interface Nodes	**1**	node
PI Interface Scan Rate	**0,00100**	sec (1000 Hz)
Measurement Data Type	**float32**	(6-digit precision)
Average Data Compression	**50**	% (2:1)
Online Data Time Range	**4**	months
Estimated Snapshot Rate	300.000	events/sec
Estimated Event Size (on Disk)	9	bytes
Estimated Archiving Rate	150.000	events/sec

STORAGE		
Minimum Archive Size	780	MB
Recommended Archive Size	**2**	GB
Required Online Disk Space	**13**	TB
Estimated Archive Count	19.828	files/year
Estimated Archive Volume (per server node)	4.635	MB/hour
	3.305	GB/month

PI Collective Nodes	**1**	node (no HA)
Estimated Bandwidth per Interface Node	8.789	KB/sec
Active Client Applications	**5**	applications
Average Query Interval	**2.400**	seconds
Average Query Range	**8,0**	hours
Average Points per Query	**100**	points
Estimated Archive Query Rate	3.000.000	events/sec

PROCESSOR		
Minimum CPU Count	5	cores†
Recommended CPU Count	**8**	cores†

(†) Physical, not logical (Hyper-Threaded) cores, or 100% allocated virtual CPUs

MEMORY		
Minimum RAM	2.340	MB
Recommended RAM	**6**	GB
Estimated Cache Capacity	1	hour
Estimated Cache Efficiency	11	%
Non-Cached Archive Reads	.668.600	events/sec

DISK I/O		
Minimum Disk Bandwidth	2	MB/sec
Minimum Disk Throughput	3.000	IO/sec*
Recommended Disk Bandwidth	**30**	MB/sec
Recommended Disk Throughput	**3.900**	IO/sec*

NETWORK		
Minimum Bandwidth‡	1.000	Mbps
Recommended Bandwidth‡	**1**	Gbps

7.4 Hardware and license costs estimation

The following table is preliminary cost estimation of the overall system.

Item tiype	Description	Amount
License	PI Server: one collective for 5000 Tags, 13 users (one partner?)	€ 100.000,00
Server	2x Intel® Xeon® X7560 2.26GHz, 24M cache, 6.40 GT/s QPI, Turbo, HT, 8C, 1066MHz Max mem	€ 15.000,00
Storage	Dell PowerVault MD1200 (20TB)	€ 12.000,00
Networking	Fiber optic switch	
Cabinet	Server cabinet	€ 1.500,00
	Total costs	**€ 128.500,00**

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ANNEX I. TECNALIA's DAS system description

tecnalia Inspiring Business

www.tecnalia.com

DAS

Distributed Acquisition System

TECNALIA RESEARCH & INNOVATION
& THE POLYTECNICAL UNIVERSITY OF
LA ALMUNIA DE DOÑA GODINA (UNIVERSITY OF SARAGOSSA)
C/ Mayor s/n 50100 La Almunia de Doña Godina - 50100 Zaragoza
January 2012

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TOPOLOGY PROPOSAL FOR A VERSATILE DISTRIBUTED DATA ACQUISITION SYSTEM FOCUSED ON OFFSHORE WIND POWER MONITORING

REFERENCE - VERSION: **V1.0**

CLIENT:

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POST CODE - CITY: **50100 La Almunia de Doña Godina** **PROVINCE/COUNTRY:** **SARAGOSSA - SPAIN**

DATE: **11/04/2011**

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1.- INTRODUCTION

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1.1.- Considerations on Offshore Wind Power.

Today Offshore Wind Farms (OWF) are increasing their role as the wind power of the future. Marine enclaves show many advantages in comparison with terrestrial locations, which include:

New and better locations (the possibilities are nearly exhausted on land).

Better wind power quality, lessening the effect of wind shearing; the wind is more uniform and less turbulent. This results in an improvement of the machines and reduces vibrations, thus increasing its useful life.

All this justifies the installation of higher-power machines than those used in land plants, resulting in higher energy production.

For these reasons, the potential development of wind farms in marine locations is significantly higher than in land locations. However, marine locations entail certain problems such as:

The complexity of installation, maintenance and dismantling increases in offshore wind turbines that require the use of ships and floating cranes. This increases the costs of the aforementioned operations and, in order to perform them, highly-qualified staff and specialised means of transport are essential, which may not always be available.

The marine environment is much more aggressive for the machines' operations since it implies incurring in additional costs, facing greater corrosion, and enduring humidity and salinity conditions, etc. which are not found in land wind turbines.

Foundation laying in shallow waters or anchoring in deep waters adds further difficulties.

Wind turbines are subject to strong storms, frost and snow, tides and marine currents, which difficult or prevent accessibility, affecting its useful life. This leads to the existence of "time windows" in which these machines can be accessed for maintenance.

Machine maintenance and access costs are much higher. As well as transporting pieces and their placement.

The problems stated above justify massive monitoring of machines and installations and their maintenance by means of complex techniques, including:

- **Preventive Maintenance.** Planning is based on the data provided by component manufacturers and in the reliability of subsystems and components.

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- **Corrective Maintenance.**

- **Smart maintenance** applied to:
    - Structures, blades, foundations, anchors and fixing elements, applying Structural Health Monitoring (SHM) techniques.
    - Maintenance of mechanical, electromechanical and electrical subsystems and components and control elements, through Machine Condition Monitoring (CM)-based techniques.

Smart maintenance allows the identification of incipient errors in subsystems and components, identification of the types of errors, its location, its size and the residual life of the subsystems, components and structures and allows a proactive maintenance management planning.

For these reasons, it is convenient to perform intensive monitoring of wind turbines subsystems and components. Such monitoring should be are robust, flexible, resistant to the marine environment and compatible with smart maintenance.

The development of this monitoring system will allow the availability of an initial data storage and transmission system, for the generation of threshold alarms and basic processing, with a great potential for their development as a smart maintenance system.

1.2.- Characteristics of an Offshore Wind Power Monitoring System.

Next the characteristics to be included in an offshore machine maintenance system are described.

- **Hardware topology - Centralised Systems vs. Distributed Systems** A centralised system has a "distribution point" from which all the wires leading to sensors/conditioners derive. This implies large wiring harnesses to be connected. On the other hand, a distributed system launches only one cable, to which nodes are connected to perform monitoring. These nodes are located in the proximity of measuring points. Although there will be specialised nodes in other tasks, currently we can say that these nodes will be connected to the sensors located in their proximity. These will be smart sensors, with direct interface to the distributed communication bus.

The advantages of distributed data acquisition systems for wind turbine monitoring are derived from:

- **Nacelle and tower sizes and number of variables to monitor.** Given the size of the nacelles of these machines (e.g. the size of a 5 MW Repower nacelle is: 19 m x 6,5 m x 6 m), the existence of a submerged part of the structure and the amount of sensors to be placed requires the distribution of the monitoring system on a hardware level. This way an easy connection system is achieved, which means simpler installation of the monitoring system (and therefore, of the machine), improving the maintenance of the monitoring system. This results in considerable savings. Wiring length will significantly decrease. Since the cables must be transported to the machines, there will be significant savings in transport costs. Cable weight will be reduced.

- **Sampling frequency.** A centralised system requires constant monitoring. For this reason, sampling frequency is adapted to that of sensor to be sampled more frequently, resulting in an excess dimension of the collected data. When working on all the variables at high frequencies, the overall price of the system's hardware grows in comparison with the price of the distributed system, in which the frequency of each node adapts to its needs.

- **Compatible with smart maintenance.** As mentioned above, and considering the offshore conditions, the cost of the installations and the machines, the energy that these machines stop producing during breakdowns and the access difficulties for maintenance, it is considered convenient to perform an intensive smart maintenance of these machines. This includes all the structures, subsystems and components comprising them. Monitoring systems will supply data for maintenance accomplishment; therefore the monitoring system should consider complying with this function and being compatible with this maintenance. This has certain implications. For this purpose, all the nodes are designed to guarantee compatibility and it is advisable to have pre-processing nodes enabling feature extraction and more elementary pre-processing techniques. This requires a distributed system on a software level.

- **Open**. Hence we can easily add new nodes, without modifying the monitoring programme code. We could even replace a node with a new one without having to shut down the system. Openness implies the capacity of enlarging and developing the system adding new functionalities; in other words, the system can evolve.

- **Easy configuration.** Through the execution of script commands without having to reboot the system.

- **Multifunctional.** By allowing the coexistence of different sensor technologies, such as conventional sensors, optical fibre sensors, actuators/sensors of piezoelectrical patches for structural analysis by Lamb waves or electromechanical impedance,

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imaging in the visual and infra-red spectra, ultrasonic acoustic sensors, remote interrogation systems, etc.

As far as we have been able to verify, there are no evidences that there is any marketed system including all these features.

1.3.- Potential variables to monitor.

Some variables to be included in the monitoring system could be:

- Deformation of components.
- Torque in low power axes through extensometry and telemetry, and in high power axes by optical systems.
- Component displacement, speed and acceleration. Axes orbits by induction and proximity.
- Component vibrations by piezoelectrical accelerometers.
- Structural deformation based on extensometry or fibre optic (blades).
- Analysis of composite defects by Lamb waves or tension maps.
- Defects in metallic structures by electromechanical impedance.
- Component temperature: contact /non-contact methods.
- Nacelle and blade orientation. Rev counting and cable winding.
- Rotor speed by infra-red or induction.
- Tower tilt.
- Status of the submerged structure.
- Tension of mooring cables.
- Cable anchoring status.
- Fluid measurements: pressure, level, temperature, filter clogging, etc.
- Lubricant measurements: ferrous and non-ferrous particle count, contamination, etc.
- Measure of structural corrosion.
- Three-phase current and voltage.
- Generated power.
- Short-circuits and surges.
- Atmospheric discharges through fibre optic magnetic field sensors.
- Wind speed and direction by ultrasounds, laser or mechanical means.
- Frost on blades.
- External pressure, temperature and relative humidity.
- Weather and sea conditions: sea level, waves, currents.

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2.- DISTRIBUTED ACQUISITION SYSTEM.

2.1.- Introduction

The idea of this proposal is to develop a versatile system with distributed acquisition and processing characteristics, ideal to monitor low-frequency (50 Hz) variables, compatible with sampling high-frequency smart nodes that also allow raw variables sampling, that have the ability to pre-process signals in a pre-established interval.

Variables can be acquired in distant points and their values are stored and synchronised in a central processor and distributed later to other processors for operations such as disc-saving, HMI interfaces, remote transmission of information through telemetry, control modules or any other application or service.

The system is based on the implementation of several independent processes which operate and communicate with each other through TCP/IP, creating an abstraction to become independent of the particular physical machine and the operational system being run. The communication between these processes will be done by a proprietary protocol to be defined (DAS Protocol).

Initial implementation will be C++ on Linux OS, with a real-time kernel.

There are four types of processes:

- **Central Processor or Core:** Its main goal is to receive variables, synchronise them over time, sampling at regular intervals and storing them in the processor history. It takes care of the clients' requests and information delivery.

- **Data producer processes:** Together with those responsible for data collection from the physical sensor through a distributed network of different subsystems with the purpose of sending sample values to the central processor. An example would be a programme that reads GPS NMEA schemes via series, parses them and sends the latitude and longitude to the central processor.

- **Advanced data producers:** These interfaces with systems like Racing Bravo are developed by EUPLA, and were conceived for monitoring in marine environments (America's Cup) and used in validation campaigns with GAMESA; as well as the interconnection with different subsystems, including Wireless Smart Sensors Network,

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WSN. For example, the Racing Bravo interface achieves compatibility with developed distributed acquisition modules through CAN Bus, being able to configure and use them, providing the obtained values to the central processor. In addition to the capacity of creating virtual ports (RS232 or 485) so that serial modules can be used at a distance through an interconnection bridge.

- **Data consumer processes:** These processes access the central processor to collect data, directly from the variable or the history; to operate with them according to their needs. An example of what we propose could be a sampled data storage process in a disc (logging), saving all the information on a database or a Web server which accesses the last "X" values of the history, to show an evolution graph in the screen. Other processes that need to access variables for a larger history, for example of several days, can do it by accessing the database; this operation will be done by a software tool that consults the database history.

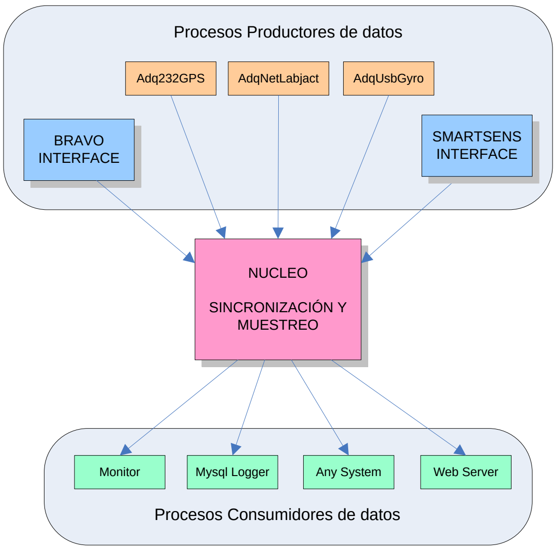

Figure 2.1

The fundamental advantages of this system, as represented in Figure 2.1, rely in the great distances between producers, consumers and core processors and the great variety of producers and consumers that allow a scalable enlargement.

2.2.- Design of Software Architecture.

The system's Vision Software, detailed in Figure 2.2., is where we observe how processes and devices are interconnected. Data consumer processes are highlighted in green, and data producers in orange and blue.

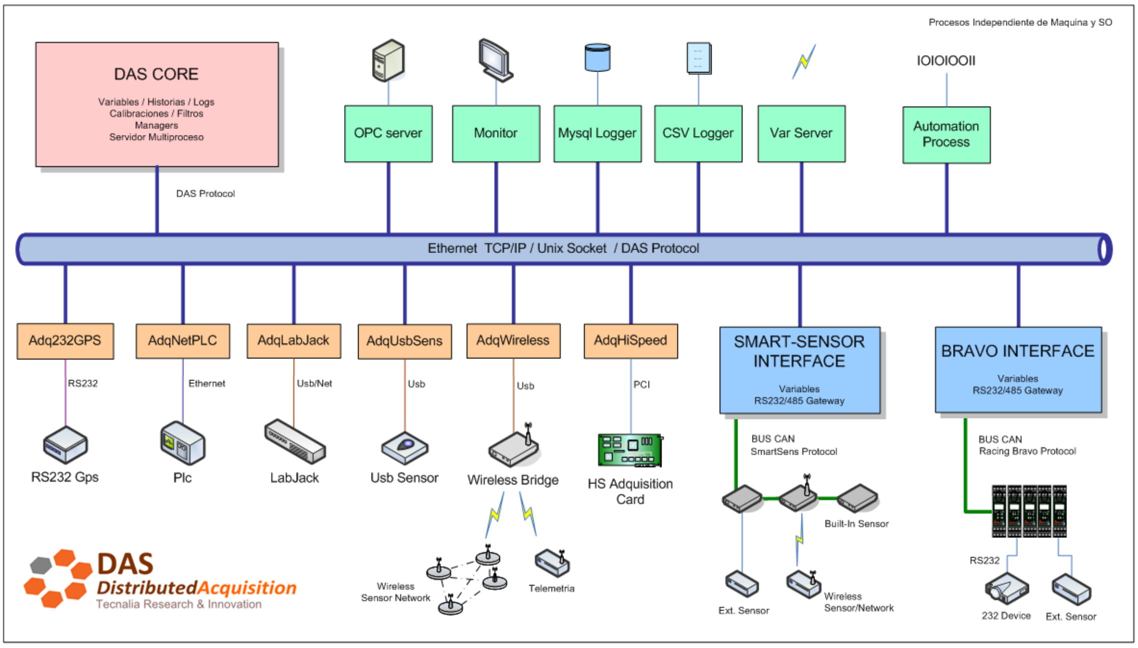

Figure 2.2

The functions of each of the processes could be detailed as follows:

2.2.1.- Central Processor.

- Is responsible for managing all the information.
- Its main goal is to receive variables, synchronise them over time, sampling at regular intervals and store them in the processor history as "scans":
- It takes care of the clients' requests for information and delivery.
- It applies filters and calibrations and calculates "formula" and "system" variables.

It has the following differentiates parts:

Variable Buffer

There are two types of variables: Natural and calculated:

- Natural: Are those variables that are established by data producing processes, these can be Boolean, Complete, Real and Text.
- Calculated: Are those values computed by the core processor in each "scan" and can be: Internal (e.g.: time) Calculated (e.g.: var_a*var_b), Evaluated (e.g.: a>b) or External (e.g.: /bin/diskfree)

There are two storage systems for variables:

- **Asynchronous mode** (like Racing Bravo): The values of the variables can reach the core processor in an asynchronous mode, and this value is introduced in the

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database. If a new value is received, it overwrites the former one. This way, the variable always has the most recent value. The frequency in which the values of the variables appear are not precise over time (since they can arrive through different buses and may suffer small millisecond delays), or in their frequency, since each device can be prepared to acquire data at different speeds.

- **Synchronised mode:** The values of the variables reach the central processor in an asynchronous way, and this value is included in a temporary buffer of "n" samples, organised by timestamp. Once the variables in the memory are organised latency problems are solved, but a problem with the process of data consumers appears which will have a relay of "x" milliseconds (a grace period so a relayed sample is placed on the buffer in the right position).

Further on a specific section will detail the design guidelines related to sampling time delay and variable synchronisation.

Natural variables, when they receive a new value, suffer a chain of operations defined by the user (calibrations, digitalisation, filtering, etc.).
Each variable stored the raw value (e.g.: volts), calibration (e.g.: Temp.), filtering and acquisition timestamp. Each of these values are accessible.

Sampling process:

Configuration will be defined in different nodes, a frequency in which to sample data. A timer is responsible for collecting "scans" of the values that vary over time, demanded at regular intervals, forming what we call a "scan" and saving them in the "history" with its timestamp.

History Buffer

The "scans" of the variables collected at regular intervals will be saved in a circular buffer, with a certain size, that will allow applications to access what's being measured in real-time, in addition to what has been measured "XX" samples before.

Log Buffer

All applications and processes will be registered in the central processor, through a circular buffer that will also be accessible and useful for the treatment of user alarms or errors.

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Managing Processors

There will be a series of processes that manage their access by means of mutex exclusion or stop lights, to provide exclusive and safe access to variables, history and logs.

Interface Process

It is responsible for serving via TCP/IP the requests of the applications that connect, defining a series of operations that can be done, like establishing the value of a variable, reading or consulting the data available in the history, etc. This will be a multi-thread process that can serve multiple clients simultaneously.

2.2.2.- Data producer processes.

These applications, connected to the central processor by means of a defined protocol, are capable of delivering the value of the acquired variables that they are responsible for. Communication will be done via TCP/IP, using domain-sockets if these were in the same system.

When these processes are initiated they will connect to the central processor; each process will greet, authenticate, perform a real-time synchronisation and exchange the necessary information so that it can periodically report the value of an acquired variable, and it will later access the device/sensor and perform infinite measures communicating the acquired values.

Each producer process is independent from others and the programming will be relatively simple, since they will be responsible solely for sending the raw value. Calibrations and filters will be performed in the main processor. We intend to create APIs for quick application development in several languages an on several OSs. The dynamic of future system enlargements, supporting new devices and sensors, are developed on the basis of a creation of new producer processes.

In the case of processes using high-speed acquisition systems (vibration analysis, etc.), it could be considered by means of nodes with pre-processed capacity; variables to be stored in the core are not those directly acquired, but other low-frequency ones, obtained from the corresponding calculation and/or analysis algorithm, for example, FFT application on an interval of acquired samples to obtain a spectrum of frequencies in this signal.

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Bravo Interface

This process or application is responsible for the compatibility of the Racing Bravo System. There is a peculiarity in the use of Racing Bravo series modules; the process creates a bridge between the serial device and the process that will be used. The process is as follows; first a TCP/IP communications port is created, through which any programme accesses the port and records data, which are sent to the serial device and the characters received in the extreme of the module are sent to the TCP/IP port.
Thus, a process can connect to the identified TCP/IP port, sending and receiving the commands with a power source physically connected to the serial port.

2.2.3.- Data consumer processes.

These applications, connected to the central processor through a defined protocol, are capable of receiving the value of the acquired variables and the history of the variables and logs.

Each application may have a different purpose for the data, thus, for example, a process can be dedicated to save data on disc, while another serves these data via Internet, another shows them on a monitoring console, etc.

For example, an "appMysql Logger" application will perform the following operations: It connects to the core, greets and receives information on variables, it requests information on the available history, and requests reception of the history data, referring by line identifiers from first to last, saving the information on "MYSQL", repeating the operation. Each time that the history is requested, it is done from the last received value in the previous operation to the last available value.

2.2.4.- Configuration file.

For all the processes to work properly, each of them has to be detailed in a configuration file. This file will indicate global variables such as the IP address and the main processor port, the definition of variables and the necessary configurations so that each application works appropriately. As an example, we could establish the configuration of Racing Bravo acquisition modules or the bauds of the serial port of a power source.

It would look like this, trying to achieve certain similarities with a Windows INI file:

```
[windspeed]
from=bravoServer:windspeed
type=real,Hz,m/s
filter=median:10
```

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```
calibration=linear:5:-10
name=wind speed bravo

[adq232gps]
core=localhost:6186
port=/dev/ttyS0,9600,8,n
pub=latitude,longitude,speed,direction,fix

[mysqlLogger]
core=ip2:por
db=ip:user:pass:db:table
history=hist10
rate=5
atocreate=false
save=time,latitude,longitude,volts,frequency
```

Configuration interface

The treatment and maintenance of configuration files, especially if the system is complex, is not simple and barely practical. To simplify these processes, we have designed a Web-based friendly configuration interface; in other words, the acquisition status and its configuration is done in the same way as a router or a printer, through a Web site.

This system will also provide advantages to access its configuration from any computer and with any device (PC, Laptop, a mobile phone or tablet pc).

Figure 2.3 below shows an example of the appearance of a Web interface.

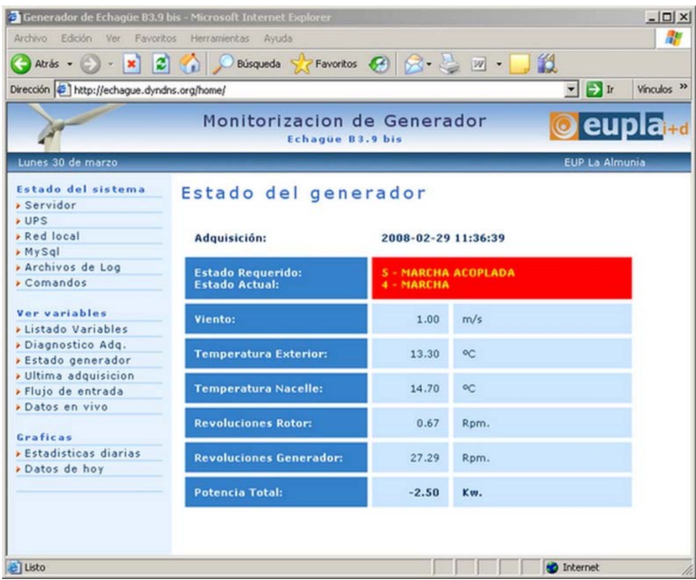

Figure 2.3

2.3.-Ethernet Communication

Communication between processes and applications is performed through TCP/IP via an Ethernet network. However, when this connection is done on the same Linux equipment, the connection is done through "Unix-Domain Sockets". Since these do not share a physical medium they lack latencies, being quicker and safer.

We must consider that in most scenarios these processes would be on the same equipment.

Perhaps, the only disadvantage of the distributed system is the problems that could arise from the latencies of this bus. To minimise its impact a Gigabit network can be used, avoiding passing through firewalls and routers, or providing several network interfaces for the system: a bus for data producers and another bus for consumers. However, these latencies refer to timings measured in milliseconds which, in the case of sampling low-frequency variables, do not affect the sampling frequencies used by the system.

Another novelty to be included is the emission of timestamped information; in other words, having a stamp showing the time of acquisition so any possible delays in the bus are corrected by the central processor.

The Ethernet network can be extended by 802.11 or Wi-Fi access points, for the connection of maintenance Wi-Fi systems or 3G routers, which offer more opportunities for the system, allowing remote connection from the telephone network.

Communication protocol

A proprietary protocol will be detailed for communications between processes, similar to the Racing Bravo RBSP protocol, through which the processes perform, among others, the following operations:

- Greeting, authentication, validation, and time synchronisation.
- Collection of information on variables and the system in general.
- Set/Read/Subscribe the value of variables.
- Read the history data and the log register.

We intend to programme API libraries for a quick development of these applications in several languages and OSs (C, C++, Java, Delphi, PHP, etc.).

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2.4.- Synchronisation and Timing.

Below, the sequence of the "trip" of a variable from the sensor to the database is itemised, illustrated in a graphic in Figure 2.4. As an example, we will present a process called “Adq232xtr”, which will be responsible for acquiring voltage, frequency and intensity values of a power source by serial port.

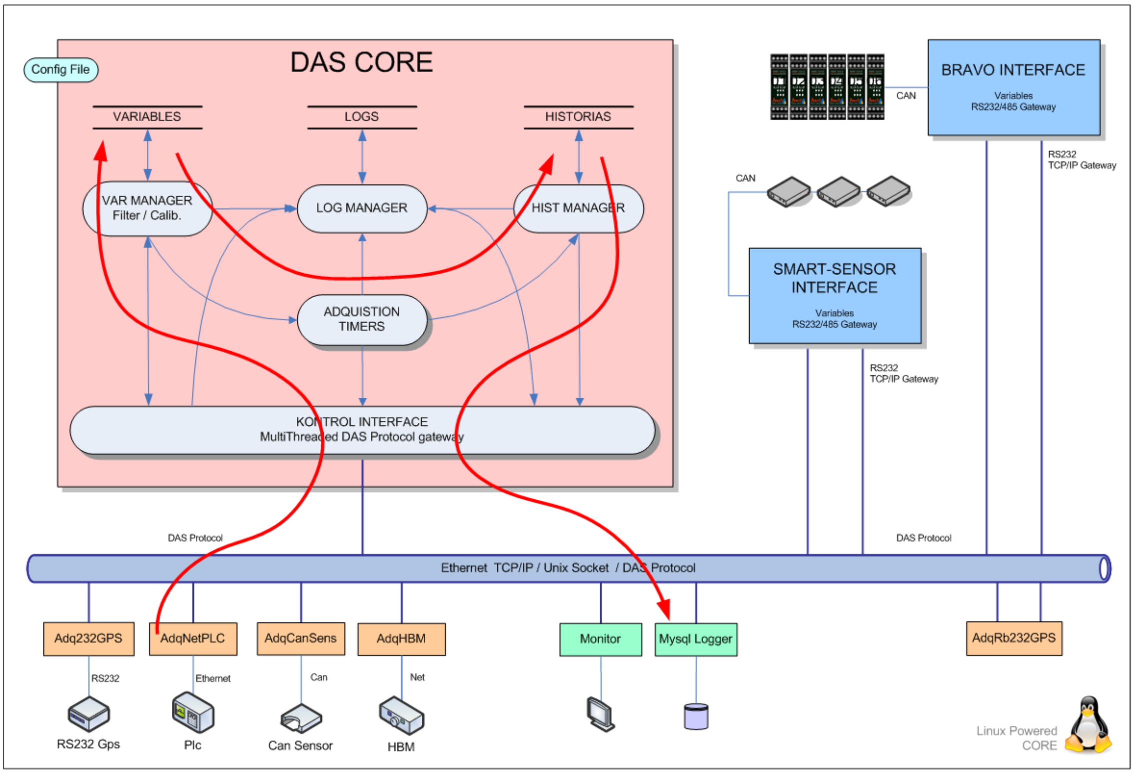

Figure 2.4

- The core starts-up and initiates the variable according to its definition in the configuration system.
- The Adq232xtr process initiates and communicates with the core, greets and negotiates the names of the variables to be provided. It opens the serial port and connects to the power source, sending the corresponding SCPI command (:MEAS:VOLT?) and obtains an ASCII response (2.3345) which is interpreted as the output voltage. The value is sent to the core by means of a specific protocol and under the agreed name. The process repeats the acquisition operation and sends the variable indefinitely.
- The core receives the variable and saves it, when it receives a new one, it will rewrite it over the previous value, always having the newest one. The core has a Timer sub-process, defined in the configuration, that every "XX" ms (the indicated frequency) saves a clip of all the variables, together with the timestamp, producing an acquisition. This operation is performed indefinitely, saving the acquisitions in a

circular buffer (of a certain size) called "history" and which may be accessed by the processes.

- The "MysqlLogger" process, which is on another machine of the network, makes the greeting and receives information on the variables. It requests information on the available history and requests the data of the history referring to line identifiers from the first to the last, saving the information on the database. It repeats the operation and each time that it requests the history it is done from the last received value in the previous operation to the last one available.

Generation of history

The synchronisation of all the variables is complex given the system's distributed architecture. As presented on the illustrated graph on Figure 2.5, which shows how the values of the variables arrive at the central processor and which values are used for each "scan" at a sampling frequency of 100Hz, t=0.01 sec.

This illustrative example refers to the acquisition of an analogous differential module of the Racing Bravo system of four channels. We must consider that this module is able to acquire 100 samples per second, distributed in 100 m/s for 1 channel, 50 m/s for 2 channels, or 25 m/s for 4 channels.

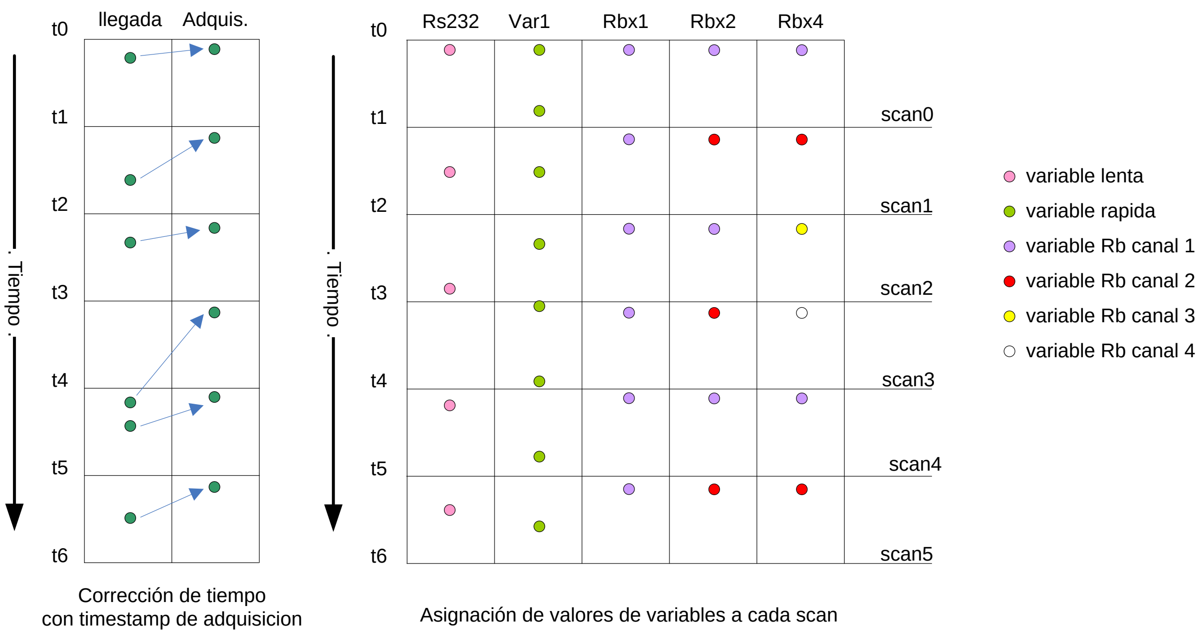

Figure 2.5

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Table on the left:

- The arrival column, represents the time in which the variable arrives at the central processor.
- The acquisition column, represents the order that the variable will occupy in relation to the timestamp in which it the sample was taken or the acquisition timestamp. (This timestamp is provided by the data producer processor; should it not be provided, the processor will assign a timestamp at the time of arrival)

Table on the right:

- The points represent the arrival of a value in the time line of the acquisition.
- At the right we can see the time at which the clip of the variable has been taken (Scan).
- The stored variable for the scan will be the last one received from those variables closer to the scan time, that should be between the previous scan and the current one (the ideal situation). However, it might be possible not to have a new value between two scans or even to find more than one. In this case it is solved in the following way:
  - Less samples than desired (slow devices RS-232) the value of a scan will be the same as the previous scan.
  - More than one sample, the newest one will be saved.

2.5.- Design and description of Hardware Topology.

2.5.1.- Interrelation between Hardware and Software processes.

Each process, either data consumption or data production, is connected to the central processor through Ethernet network, but this process usually requires dealing with a data acquisition system, a sensor or some other type of device or hardware.

Thus, for example, the process collecting data from a power source is connected through a serial port, a process that acquires a Labjack or HBM sub-system does so through Ethernet, and the process getting them from Racing Bravo uses a CAN Bus.

Each producer process accesses its device through the appropriate communication line and controls it through the necessary libraries and protocols, providing the core with the measured data. In this way, the central processor does not dialogue directly with any hardware, which solves its incompatibility problems and the drivers of other systems, and the consumer processes use this data regardless of their source and their method of acquisition.

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Potential devices and integrable hardware.

- External USB acquisition systems, like LabjackUE9, or the high-speed National NIUSB6259, GPS, with wireless sensor networks (WSN), etc.
- Ethernet devices, such as acquisition systems, Fibre optic interrogators and PLCs.
- CAN devices, like the Racing Bravo acquisition modules, new modules to be developed or future SmartSensors.
- Series Devices.
- PCI/ISA data acquisition cards.
- PLC and automatons, via Profibus, Modbus, Interbus, etc.
- Embedded systems and ARM-based cards, like BeagleBoard or IGep, with Linux Embedded S.O.
- Any hardware that is capable of communicating with the producer/consumer process.

Figure 2.6 shows the interconnection topology of different subsystems with different communication interfaces managed by processes which acquire information and send it through the Ethernet network to the core.

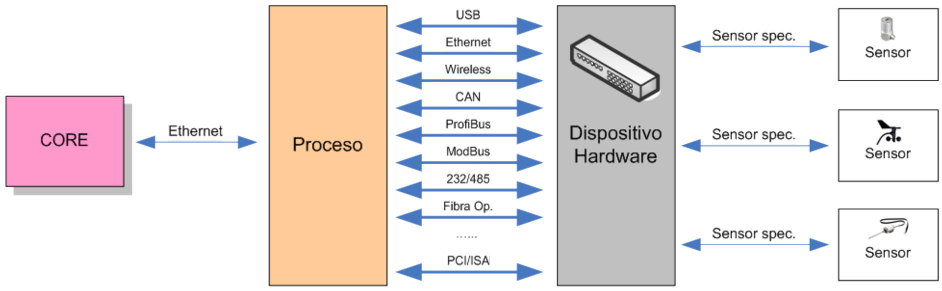

Figure 2.6

The following example, illustrated in Figure 2.7, shows how acquisition and consumption processes are distributed in different computers and systems, and with different connections.

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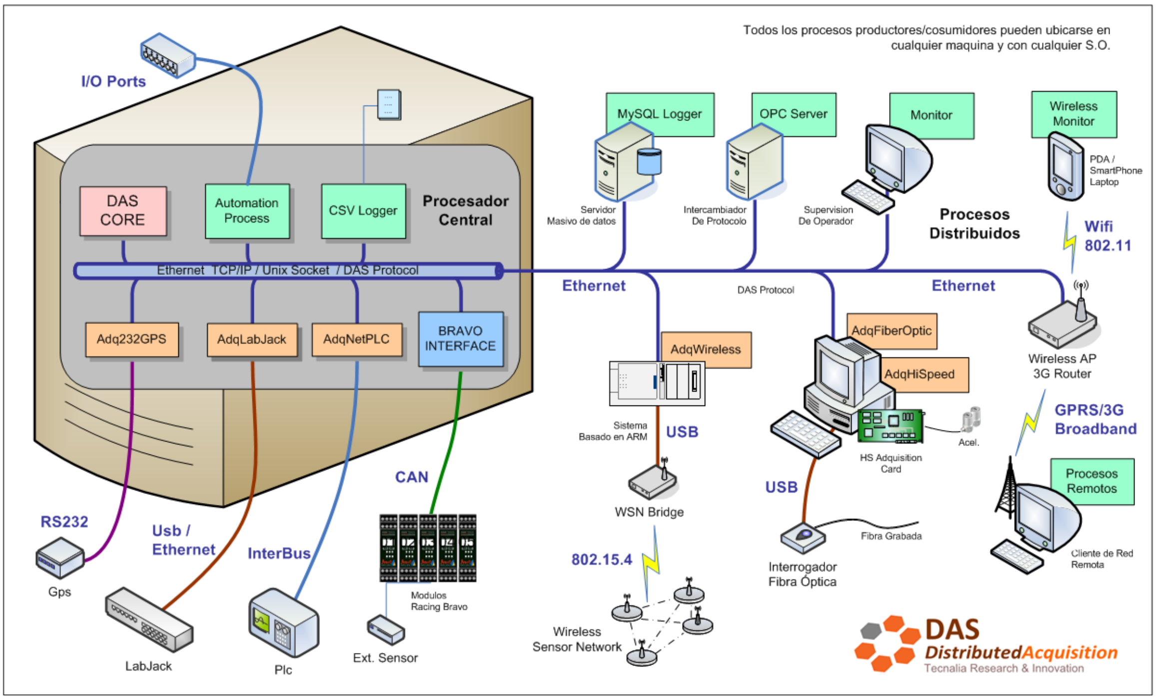

Figure 2.7

2.5.2.- Challenges of the DAS HW.

- **Easily expandable.** The addition of new acquisition channels is simple and does not depend on the device's rack. Sometimes centralised systems may be expandable but have a limited physical space that could be exceeded. In this case, a new investment would be necessary to enlarge the rack.

- **Less wiring.** For obvious reasons this type of distributed system just requires wiring for the communications bus and the power source.

- **Quick installation.** This parameter is essential for field monitoring, since it is probable that the machine is active and should have the least downtime possible.

- **Lesser weight of equipment.** The reduction of copper lines reduces installation weight.

- **Minimal intrusion.** The interference of the installation of the monitoring device in the maintenance cycle and machine operations should be avoided as much as possible.

- **Greater portability.** These more manageable acquisition modules are easier to transport, and try to avoid dependence on great racks and complex patching connections.

- **Ease of connection.** In centralised systems the chances of connecting something where it shouldn't be connected is quite high.

- **Greater tolerance to noise.** The longer the cable transporting a signal, the greater the probability of interferences by local devices.

2.5.3.- Hardware Topology.

Next, Figure 2.8 explains the philosophy of the distributed acquisition system topology, in which the different modules vertebrating the hardware architecture are described.

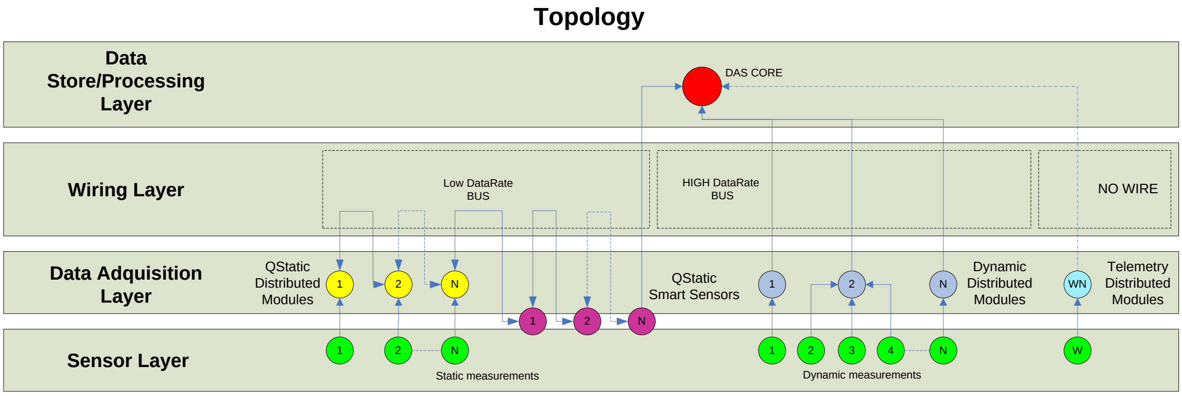

Figure 2.8

The different types of modules that make up a system could be, basically, the following:

- **DAS CORE.** Central module responsible for information management, synchronisation and storage. It also takes care of the clients' information requests and delivery.
- **QStatic Module.** Quasi-static data acquisition module. Devices focused on variables with a sampling frequency not exceeding 50Hz.
- **QStatic Sensor.** Acquisition module with embedded sensor; the device has a measuring element and the necessary conditioning and filtering elements for data collection.
- **Dynamic Distributed Module.** Dynamic data acquisition module. Focused on variables with frequency exceeding 50Hz.
- **Telemetry Distributed Modules.** Telemetry modules for uses where it is impossible to lay a cable reaching the sensor, like in mobile axes, for example.

2.5.4.- Topology of DAS modules.

Next an overview of the features of the different modules that could basically make up the DAS hardware topology is described.

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QStatic Module.

Quasi-static data acquisition module. Devices focused on variables with a sampling frequency not exceeding 50Hz. Based on the design of an expandable terrace, the module would be capable of having the following interfaces:

- Terrace for reading voltage sensors.
- Conditioning terrace for extensometric sensors.
- Conditioning terrace for sensors based on the power link.
- Terrace to detect changes in digital status.
- Communications terrace for sensors with integrated electronics (GPS, IMU, etc.).

The module will communicate through a field BUS (Bus CAN) with DAS. Figure 2.9 shows the blocks of the QStatic Module.

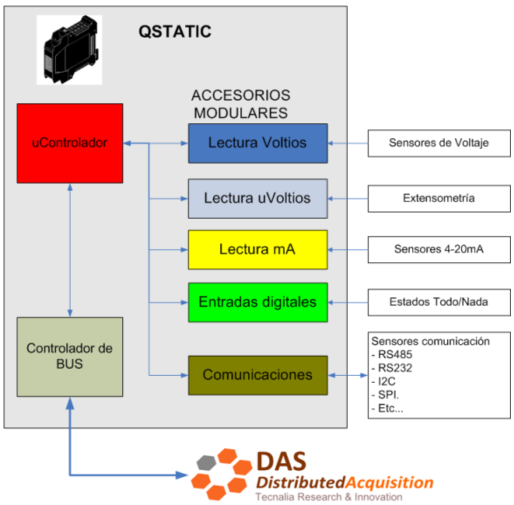

Figure 2.9

QStatic Smart Sensor.

Quasi-static sensor module. The device integrates the sensor within its structure thus simplifying the device's installation. As the QStatic module, the sensor's acquisition frequency will be equal or below 5Hz.

The module will communicate through a field BUS (Bus CAN) with DAS. Figure 2.10 shows the blocks of the QStatic Smart Sensor module.

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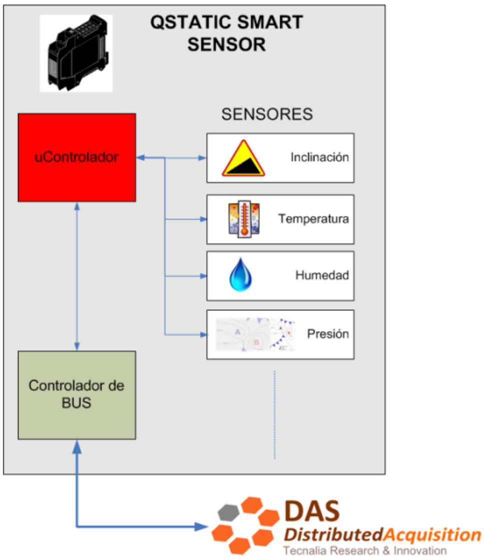

Figure 2.10

Dynamic Module.

High-frequency variables acquisition module with a bandwidth not exceeding 20Khz. Depending on the utility, the module will have a conditioning phase that tolerates:

- Sensors with an output response expressed in volts.
- Extensometric sensors.
- Accelerometers.
- Etc.

Due to the elevated response bandwidth of the sensors in the DAS interface it will be done via ETHERNET. Figure 2.11 shows the blocks of the Dynamic Module.

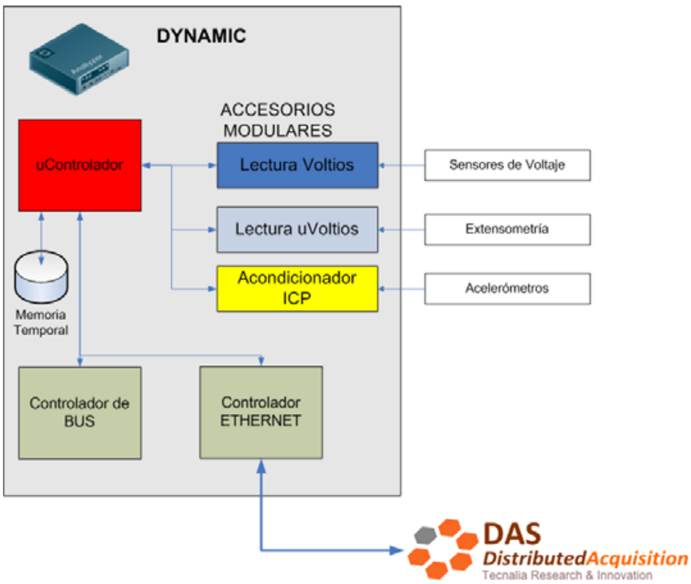

Figure 2.11

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Dynamic Processor Module.

Adaptation module of the Dynamic Module. Although the module has the features of the interface with the sensor technology of the aforementioned module, data calculation and pre-processing possibilities for the extraction of the main components of the signal (PCA) are included as an enhancement. When a feature extraction and selection process is performed, a high bandwidth communications BUS will not be necessary, preferring a field BUS, such as the CAN Bus of the DAS. Figure 2.12 shows the blocks of the Dynamic Processor Module.

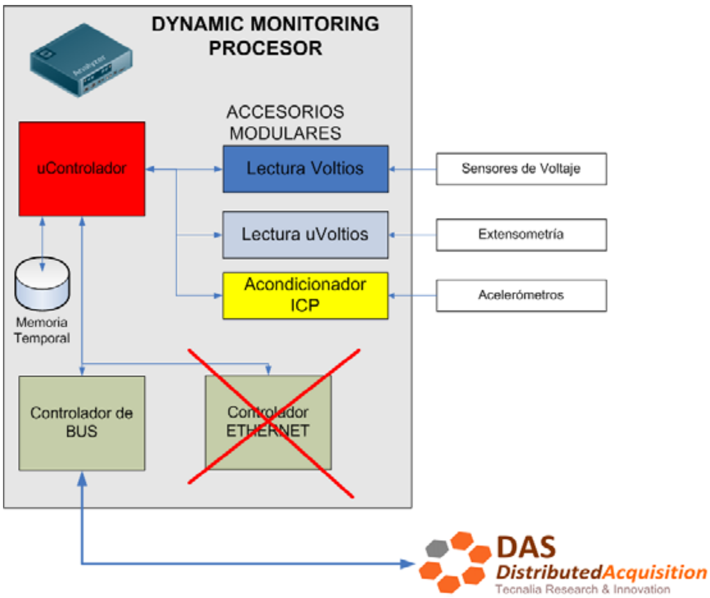

Figure 2.12