Project no.223975

MOBESENS

Mobile Water Quality Sensor System

Instrument: *Please tick*	~~CA~~	STREP	~~IP~~	~~NOE~~

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D1.1 – Requirements for Lakes, Sea and River systems

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System Requirements

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Author(s)	:	Jordi Cros, Marilou Tercier, Jean-Luc Loizeau, Alain Grisel, Paul Muralt, Martin Seneclauze, Philippe Dallemagne, Andreas Hutter, Paul D. Mitcheson, Loic Dussud, Djamal Zeghlache

Abstract

MOBESENS provides a modular and scalable ICT based solution for water quality monitoring, gathering quickly and reported across wide areas.

For alert detection and data analysis, low power wireless sensor network gathers data samples that are entered in the grid based information system with position and time stamp.

Some elements of MOBESENS networks are capable of navigation and both surface and subsurface measurements.

Keyword list

Mobility, navigation, low power, grid information, sensors

1 Objective

Management of the environment for predictable and sustainable use of natural resources is one of the great challenges of the 2lst century. Although water covers most of the planet, it is becoming increasingly difficult to ensure adequate supplies of fresh, clean water for drinking, as well as, for sports and wellness activities. The demand for water resources is increasing as the population grows. At the same time, water resources are increasingly exposed to pollutants and spills as parts of the world become ever more crowded and industrialised. Potential climate changes due to global warming may also impact water resources.

Management of water quality requires regular measurements and monitoring. Today, measurements of water quality are performed manually. The process can be slow and painstaking. Multiple point measurements are needed to cover an area. The process needs to be automated and extended to provide rapid and effective monitoring. Autonomous, mobile and self-healing solutions are needed to identify trends and to help localize and track potential problems.

MOBESENS provides a modular and scalable ICT based solution for water quality monitoring. It enables data to be gathered quickly and reported across wide areas. The low power wireless sensor network gathers data samples, which are time and location stamped and automatically entered into the grid based information system to facilitate analysis and issue alarms if needed. Mobility is a unique feature of MOBESENS, which are capable of navigation and both surface and subsurface measurements. This extends range, enables 3D area measurements and facilitates operation, even in bad weather. MOBESENS may form ad-hoc networks enabling rapid and reliable reporting as well as relative localization and tracking (e.g. of contaminants). Opportunistic communication between MOBESENS and both fixed and mobile buoys is envisioned. Renewable energy sources are studied for self-sustained MOBESENS operation.

2 Introduction

The present document is the system requirements of the MOBESENS project, needed to implement the solution. As some requirements will only be defined as projects goes on, the present document is not static or definitive, and during the development of the MOBESENS project will be actualised.

In order to make the identification of system requirements for different types of water monitoring systems, some points must be taken in account:

- Why to measure. In the MOBESENS project, the objective is to get autonomous, mobile and self-healing network for water quality monitoring for alert. This means that not only the accuracy of the measure is important, but also its availability in near real-time. And in order to detect and alert - a value that differs from the normal value -, may be more important to have the good data (reliability of measurement is of prime importance to decide is the data differ from normal value or is an error in measurement) than it’s precision.

- What to measure. The ideal objective is to get a measurement of all parameters, but in the real world this process has a cost depending on the parameter and the frequency of the measurements: some parameters are low cost (as temperature) but others, as explained below are high cost. The selection of parameters to measure must take in account previous acknowledge of place where system will be installed, the state of the art, and the cost/benefit analysis: for example, it is more interesting to measure pH at the input of a waste water treatment plant than at the output, but the measurement of phosphates is more important at the output than at the input. MOBESENS will provide a solution for water quality monitoring for some of the defined parameters in the Water Framework Directive.

- Where to measure. In the MOBESENS project, three scenarios have been defined (as explained in *Chapter 3 Scenarios*): the system in lakes; the system in marine coastal areas; and the system in rivers. In these three scenarios, even though the objective is the same (water quality monitoring for alert), the situation and number of points to be measure are different.

- When to measure. As before, the ideal objective is to get a continuous value for all measures, but there are two issues: first, the volume of information generated may increase the cost of communications, storage and processing elements; second, some sensors and/or analysers can not work in a continuous way. So, depending of the scenario and the state of art, the acquisition time must be defined.

2.1 The Water Framework Directive

The Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy Water Framework - also known as the Water Framework Directive (WFD) - is a European Union directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies, including marine waters up to kilometre from shore, by 2015. The WFD is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach.

The directive defines 'surface water status' as the general expression of the status of a body of surface water, determined by its ecological status and its chemical status. Ecological status refers to the quality of the structure and functioning of aquatic ecosystems of the surface waters. Good ecological status is defined locally as being lower than a theoretical reference point of pristine conditions, i.e. in the absence of anthropogenic influence.

The Quality elements for the classification of ecological status defined in the WFD are:

- Rivers
  - Biological elements
    - Composition and abundance of aquatic flora
    - Composition and abundance of benthic invertebrate fauna
    - Composition, abundance and age structure of fish fauna
  - Hydromorphological elements supporting the biological elements
    - Hydrological regime
      - quantity and dynamics of water flow
      - connection to groundwater bodies
    - River continuity
    - Morphological conditions
      - river depth and width variation
      - structure and substrate of the river bed
      - structure of the riparian zone
  - Chemical and physico-chemical elements supporting the biological elements
    - General
      - Thermal conditions
      - Oxygenation conditions
      - Salinity
      - Acidification status
      - Nutrient conditions
    - Specific pollutants
      - Pollution by all priority substances identified as being discharged into the body of water
      - Pollution by other substances identified as being discharged in significant quantities into the body of water

- Lakes
  - Biological elements
    - Composition, abundance and biomass of phytoplankton
    - Composition and abundance of other aquatic flora
    - Composition and abundance of benthic invertebrate fauna
    - Composition, abundance and age structure of fish fauna
  - Hydromorphological elements supporting the biological elements
    - Hydrological regime
      - quantity and dynamics of water flow
      - residence time
      - connection to the groundwater body
    - Morphological conditions
      - lake depth variation
      - quantity, structure and substrate of the lake bed
      - structure of the lake shore

    - Chemical and physico-chemical elements supporting the biological elements
        - General
            - Transparency
            - Thermal conditions
            - Oxygenation conditions
            - Salinity
            - Acidification status
            - Nutrient conditions
        - Specific pollutants
            - Pollution by all priority substances identified as being discharged into the body of water
            - Pollution by other substances identified as being discharged in significant quantities into the body of water

- Transitional waters
    - Biological elements
        - Composition, abundance and biomass of phytoplankton
        - Composition and abundance of other aquatic flora
        - Composition and abundance of benthic invertebrate fauna
        - Composition and abundance of fish fauna
    - Hydro-morphological elements supporting the biological elements
        - Morphological conditions
            - depth variation
            - quantity, structure and substrate of the bed
            - structure of the intertidal zone
        - Tidal regime
            - freshwater flow
            - wave exposure
    - Chemical and physico-chemical elements supporting the biological elements
        - General
            - Transparency
            - Thermal conditions
            - Oxygenation conditions
            - Salinity
            - Nutrient conditions
        - Specific pollutants
            - Pollution by all priority substances identified as being discharged into the body of water
            - Pollution by other substances identified as being discharged in significant quantities into the body of water
        - Coastal waters
    - Biological elements
        - Composition, abundance and biomass of phytoplankton
        - Composition and abundance of other aquatic flora
        - Composition and abundance of benthic invertebrate fauna
    - Hydromorphological elements supporting the biological elements
        - Morphological conditions
            - depth variation
            - structure and substrate of the coastal bed
            - structure of the intertidal zone

- Tidal regime
  - direction of dominant currents
  - wave exposure
- Chemical and physico-chemical elements supporting the biological elements
  - General
    - Transparency
    - Thermal conditions
    - Oxygenation conditions
    - Salinity
    - Nutrient conditions
  - Specific pollutants
    - Pollution by all priority substances identified as being discharged into the body of water
    - Pollution by other substances identified as being discharged in significant quantities into the body of water

The list of the main pollutants defined in WFD is in Table 1, and the list of the 33 priority substance approved by Decision Nº 2455/2001/EC of the European Parliament and of the Council of 20 November 2001 is in Table 2.

Table 1: List of main pollutants

	Name of pollutant
1	Organohalogen compounds and substances which may form such compounds in the aquatic environment.
2	Organophosphorous compounds.
3	Organotin compounds.
4	Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment.
5	Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances.
6	Cyanides.
7	Metals and their compounds.
8	Arsenic and its compounds.
9	Biocides and plant protection products.
10	Materials in suspension.
11	Substances which contribute to eutrophication (in particular, nitrates and phosphates).
12	Substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.).

Table 2: List of the 33 priority substances

	CAS number	EU number	Name of priority substance	Priority hazardous
1	15972-60-8	240-110-8	Alachlor	
2	120-12-7	204-371-1	Anthracene	X
3	1912-24-9	217-617-8	Atrazine	
4	71-43-2	200-753-7	Benzene	
5	n.a.	n.a.	Brominated diphenylethers	X
6	7440-43-9	231-152-8	Cadmium and its compounds	X
7	85535-84-8	287-476-5	C_{10-13}-chloroalkanes	X
8	470-90-6	207-432-0	Chlorfenvinphos	
9	2921-88-2	220-864-4	Chlorpyrifos	
10	107-06-2	203-458-1	1,2-Dichloroethane	
11	75-09-2	200-838-9	Dichloromethane	
12	117-81-7	204-211-0	Di(2-ethylhexyl)phthalate (DEHP)	
13	330-54-1	206-354-4	Diuron	
14	115-29-7	204-079-4	Endosulfan	X
	959-98-8	n.a.	(alpha-endosulfan)	
15	206-44-0	205-912-4	Fluoranthene	
16	118-74-1	204-273-9	Hexachlorobenzene	X
17	87-68-3	201-765-5	Hexachlorobutadiene	X
18	608-73-1	210-158-9	Hexachlorocyclohexane	X
	58-89-9	200-401-2	(gamma-isomer, Lindane)	
19	34123-59-6	251-835-4	Isoproturon	
20	7439-92-1	231-100-4	Lead and its compounds	
21	7439-97-6	231-106-7	Mercury and its compounds	X
22	91-20-3	202-049-5	Naphthalene	
23	7440-02-0	231-111-4	Nickel and its compounds	
24	25154-52-3	246-672-0	Nonylphenols	X
	104-40-5	203-199-4	(4-(para)-nonylphenol)	
25	1806-26-4	217-302-5	Octylphenols	
	140-66-9	n.a.	(para-tert-octylphenol)	
26	608-93-5	210-172-5	Pentachlorobenzene	X
27	87-86-5	201-778-6	Pentachlorophenol	
28	n.a.	n.a.	Polyaromatic hydrocarbons	X
	50-32-8	200-028-5	(Benzo(a)pyrene),	
	205-99-2	205-911-9	(Benzo(b)fluoranthene),	
	191-24-2	205-883-8	(Benzo(g,h,i)perylene),	
	207-08-9	205-916-6	(Benzo(k)fluoranthene),	
	193-39-5	205-893-2	(Indeno(1,2,3-cd)pyrene)	
29	122-34-9	204-535-2	Simazine	
30	688-73-3	211-704-4	Tributyltin compounds	X
	36643-28-4	n.a.	(Tributyltin-cation)	
31	12002-48-1	234-413-4	Trichlorobenzenes	
	120-82-1	204-428-0	(1,2,4-Trichlorobenzene)	
32	67-66-3	200-663-8	Trichloromethane (Chloroform)	
33	1582-09-8	216-428-8	Trifluralin	

2.2 The Cost of the measure

In order to determinate the cost / benefit of installing a network, the real cost of the measure must be calculated, taking in account all elements needed to get, normally in a Control Centre, a correct value of the parameter to measure.

The cost of a measure has two different parts:

- The installation or implementation cost. Is the cost of all the necessary elements for obtaining the measure the first time. Costs included are:
  - The infrastructure (pumps, buildings, pipes,…) and the installation cost. Some sensors may be placed directly in water, but some analysers may need to be installed out of water and with a special treatment system. Different analysers mounted in a big water quality monitoring station may share building, pump, filtration system, energy system, data acquisition and communications system, so some of the costs may be shared between alls measures.
  - Analyser or sensors cost. All elements necessary to get a correct value as much time as possible must be considered (auto calibration system, auto cleaning system …), but they could vary a lot depending of the type of sensor or analyser and network.
  - Communications cost. When using a commercial communications system (GSM, GPRS, VSAT …), all elements that must be acquired or hired have to be taken in consideration. But some wide area critical networks may build their own communications network, and cost of all network will be included.
  - Control Centre. Development or purchase (or hire) of hardware and software applications for data transmission, validation and analysis.

- The operational cost. Is the cost of the necessary elements to keep on getting the measures with the desired precision and accuracy. Depending of the type of sensor and network, costs that have to be included are:
  - Preventive maintenance. Depending of the network, the necessary replacement of elements before they break, change of sensors or sampling elements, replacement and maintenance of infrastructure elements (building, pumps, pipes, filtration equipments …) must be taken in account. Also, life time of some reactants may be short (no more than 7 days), so they have to be changed before degradation.
  - Communications cost must also be taken in account: in a public communication system, the operator has to be paid; in private communications system, maintenance of elements involved in making system work properly has a cost.
  - Personal cost. In a very complete quality measurement station with many complex analysers, the permanent presence of a technician may be necessary. In simple network (just 1 inspection every 6 moths), 1 technician is able to maintenance a big number of stations. Also, in the Control Centre, technician for making the analyse of received data may be necessary.
  - Displacement cost. In wide area networks, the displacement of technician to the stations will be an important part of the cost, great more if a special transport system is necessary.
  - Cost of energy must be taken in account.
  - Corrective maintenance. All the operational cost performed when a fail of instruments occurs.

As an example, some network can have a “low” cost, as measure every 15 minutes of superficial water temperature of a urban channel with GSM: sensor can be installed directly in water, temperature sensor is low maintenance sensor, displacement of technicians for preventive or corrective maintenance is short, communications cost for installation and maintenance is low, and the cost of a Control Centre for acquiring data and processing then is low.

But some networks can have a “high” or “very high” cost, for the measurement of some complex chemical or biological parameters with great preventive maintenance, or wide area networks where access to equipment is not easy (in the middle of the sea, or were far from inhabited place), or with a high cost of energy or communications.

3 Scenarios

The MOBESENS project has defined three different scenarios where the project must provide a modular and scalable solution:

- The system in a still freshwater body. Lake of Geneva will be used for evaluating the system in this scenario
- The system in sea and coastal lagoon. The Lagoon of Thau will be used for evaluating the system in this scenario.
- The system in a river. The Ebro River will be used for testing the system in this scenario.

The objective is the same for all three scenarios (water quality monitoring for alert), as the water bodies have different problems, dynamic behaviour and reaction time, the interesting parameters to measure, the place and situation to take the sample, and number and frequency of the measure will be different.

As the objective of MOBESENS project is to provide a modular and scalable solution to cover these three scenarios, the knowledge of its different needs is necessary.

3.1 The Lake Scenario

In the lake scenario, one of the most important problems is to detect substances prone to enhance eutrophication, which is the result of an increase in nutrients - typically compounds containing nitrogen or phosphorus - in water bodies, such as lakes, estuaries, or slow-moving streams. The term is however often used to indicate the increase in the ecosystem's primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.

Eutrophication is frequently a result of nutrient pollution such as the release of sewage effluent and run-off from lawn fertilizers into natural waters (rivers or coasts) although it may also occur naturally in situations where nutrients accumulate (e.g. depositional environments) or where they flow into systems on an ephemeral basis (e.g. intermittent upwelling in coastal systems). If an ecosystem receives an excess of nutrients, primary producer (algae, macrophytes,) growth is excessively stimulated. This enhanced growth, reduces dissolved oxygen in the water when dead phytoplankton and macrophyte material decomposes. It can cause other organisms to die (e.g. fish kills).

Nutrients can come from many sources, such as fertilizers applied to agricultural fields, golf courses, and suburban lawns; deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; and sewage treatment plant discharges.

Another important problem in the lake scenario is the monitoring of the temporal and spatial evolution of the concentration of trace metal species: Trace elements or compounds release from anthropogenic activities present a severe hazard to the normal functioning of the aquatic systems, as they are not biodegradable and are involved in biophysicochemical cycles and distributed in various physicochemical forms. The fate and impact of trace metals are function of the proportion of these various metal species, which in turn are function of the bio-physicochemical conditions of the media and thus may change continuously in space and time. The traditional monitoring approach is based upon discrete sampling methods followed by laboratory analysis of total dissolved concentrations of chemical elements. This approach is unsatisfactory as: i) it is very costly (i.e. specialized sampling equipment and expensive facilities such as clean rooms are needed) and time consuming; iii) it does not ensure accurate data due to contamination of the samples which may occurs during sampling and sample handling; ii) it does not provide the data frequency required for the study of trace metals in dynamic coastal ecosystems and iii) it does not allow effective monitoring of the pollution discharges into the systems with rapid remedial action. Moreover, the measurement of total dissolved metal concentrations is insufficient as it does not allow to improve our understanding of the natural processes governing metal contaminant behaviour, their transport and bioavailability, and thus the relationship between their anthropogenic releases and their long-term impact on aquatic ecosystems as well as on humans who often lay at the top of the trophic chain. Measurements of relevant (in term of ecotoxicity) specific metal species or group of homologous metal species, in real time and at appropriate time scale are required.

In order to evaluate the risk of eutrophication, measurements of parameters at several depths are used to determine the stratification of the water body. Spatial and temporal measurements of given trace metal species as a function of the bio-physicochemical conditions are required to assess the behaviour and fate of trace metals and thus their ecotoxicological impact. Based on this. the most important parameters to measure are:

- Temperature. Used to determine the water column stratification
- Dissolved Oxygen. Allows to determinate main processes occurring in the water column such as photosynthesis/respiration.
- Chlorophyll, to measures the concentration of algae.
- Metal species or group of metal species potentially bioavailable

Other possible parameters are

- Nutrients (orthophosphates & Nitrates), to determine the potential of algae grow.
- Dissolved organic matter
- Turbidity. Used as an indirect way of measure the presence suspended matter / (algaes and minerogenic particles).
- pH.
- Redox potential. Useful to determine, in conjunction with dissolved oxygen, the degree of decomposition of material in a lack of oxygen.
- Conductivity. Used to evaluate processes of dissolution of precipitation occurring in the water column, such as calcite “whitings”.
- Total dissolved metal species.

In this scenario, even the lake behaviour is dynamic, the slow variation in water body quality can be detected with only 4 or 6 daily vertical profiles of measures, with a vertical separation of 25 to 200 cm. The horizontal grid will depend of the size and lay out of lake: – form 100 to 2500 m.

For evaluation of system in lakes, the selected testing site will be the Bay of Vidy, where the WWTP of the city of Lausanne discharges its effluent. Lausanne, a city of 130,000 inhabitants on the northern lakeshore, pumps 58% of its water supply from the lake. It is also the city discharging the largest volumes of treated domestic and industrial wastewater into the nearby Bay of Vidy. The bay is impacted by three major sources of contamination (Figure 1):

- The wastewater treatment plant (WWTP), that treats domestic waters of the City of Lausanne, with a mean discharge of 1–3 m^3 s^{-1} and exceptionally up to 6 m^3 s^{-1}, depending on meteorological conditions. WWTP effluent waters are released into the bay via an underwater pipe at 30m water depth, at 700m from the shore.
- the Chamberonne River, that presently drains surface waters from its natural watershed and some untreated wastewaters.
- and the Flon storm water outlet, that collects surface and wastewater from the western part of the city, which is usually treated at the WWTP but released into the lake during strong rain events, via a conduit at 10m depth.

The drinking-water pumping station of Saint-Sulpice is located at 3.8 km west of the WWTP outlet pipe.

Published data demonstrate the accumulation of contaminants close to a city recreational area on the shore and its related ecological impact and health risks, mainly due to the presence of faecal bacteria and of sediment contamination. Several studies demonstrate the complex dynamics of the bay water circulation, which hamper a reliable prediction of the transport route of the WWTP effluent contaminants. Effluent waters are good candidate to demonstrate the ability of the mobile sensors to detect and trace water movement, as they have usually very different characteristics than the lake water (temperature, conductivity, pH,. …).

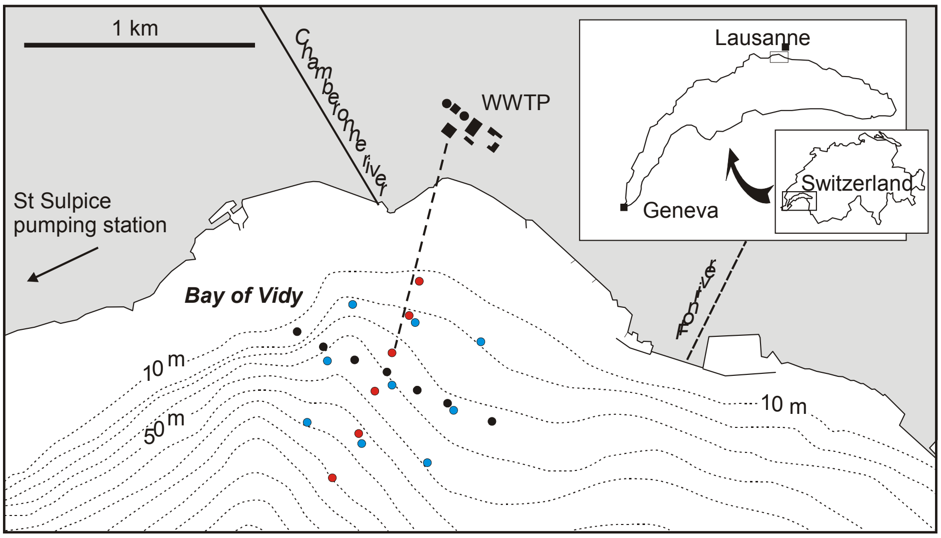


Figure 1: Possible points of measure in horizontal grid. Coloured points represent three different node layouts around the WWTP effluent.

To support the deployment of the MOBESENS system in the Bay, a hydrodynamic model of the surface current circulation in the lake has been developed. This model is based on a finite element model (SHYFEM) first developed at the Institute Science Marine of Venice by Umgiesser *et al.* (2004) [A]. Figure 2 represents the surface current in the Bay of Vidy during a north-east wind episode and a south-east wind episode.

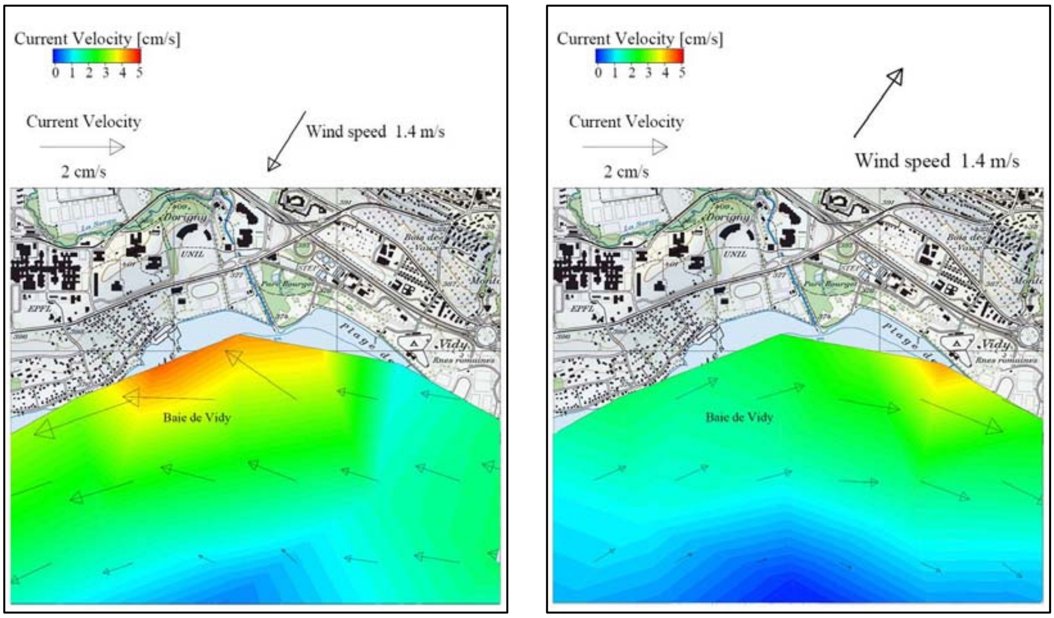


Figure 2: Modelled surface currents in the Bay of Vidy, during a north-east wind episode and a south-west wind episode. In the region of the effluent, current motion is almost at 90° to the wind direction.

Current velocity near the effluent may reach 3 cm/s, that is about 2.5km per day. This modelling tool will help to evaluate the displacement of the MOBESENS drifter during the evaluation process. On the other hand, results from measurements of MOBESENS system will increase the validation reliability of the hydrodynamic model

3.2 The Sea and Coastal Lagoon Scenario

In the coastal lagoon scenario, two environmental issues are of interest with regards to some human activities occurring in the lagoon:

- The sudden input of contaminated freshwater (faecal and chemical contaminants, nutrients, suspended matter) from the watershed due to short and heavy rainfalls that occur under Mediterranean climate. As a consequence, there are temporary and local salinity collapse (plume effect) and risks of sanitary contamination of exploited shellfishes and bathing waters.
- As Mediterranean coastal lagoon are highly productive ecosystem, if high temperature and lack of wind occur during summer period, there is an elevated risk of hypoxic/anoxic events. Anoxia, and consequent dystrophic process (i.e. sulfato-reduction) may lead to massive mortality, especially within reared shellfish stocks. An early detection of oxygen depletion could allow to reduce economic losses by displace or emerge, for example, reared shellfishes.

In order to monitor these processes the most important parameters to measure are:

- Temperature, salinity and turbidity at several depths to track freshwater plumes and potential stratification in the deeper parts,
- Dissolved oxygen at several depths to alert from hypoxia/anoxia risk,
- Chlorophyll a (fluorescence) to estimate primary pelagic biomass.

Others possible parameters are:

- Inorganic nutrients and sulphide concentrations,
- *E. coli* in water in order to evaluate the risk of bathing waters and shellfish contamination,
- speed currents (vertical profile at moored stations) Order of magnitude of currents in coastal lagoon is 5 cm/s (with max value of 1m/s near .
- turbulence measurements in low depth (less than 2m)

Coastal lagoons are highly variable environment at a daily, seasonally or annually scale. Thus, for the coastal lagoon, there is a need to have quite high frequency measurements (half hour frequency) but, for a cost efficiency objective, only values that differ from these “natural variability” should be saved and transmitted in quite real time.

With regards to spatial distribution of measurements, there is a need to settle at different place in order to take into account spatial variability of the lagoon water mass, hydrological gradient in front of river mouths, and the monitor the place where lagoon human activities take place. Vertical profile measurements should also be considered.

Due to high productivity of the ecosystem and low dynamics, biofouling of sensors need to be taken into account. Time scale of this phenomena in coastal lagoon during spring and summer time is less than two weeks.

3.3 The River Scenario

The WFD defines the "good ecological status" if there are no, or only very minor, anthropogenic alterations of the values of the physico-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions.

This means that, in the river scenario, one of the most important problems is to reach levels outside the range established because of presence of punctual contamination by spills. In this scenario, the measure of the parameters along the river gives information of where spill has began and how spill is diffused and diluted, and is used to identify the type of the contaminant(s) released in the studied water body.

The list of parameters to measure is:

- Physicochemical parameters
    - Temperature, pH, Conductivity, Dissolved Oxygen, Turbidity
- Inorganic chemical parameter
    - Ammonium, Phosphates, Nitrates.
- Organic chemical parameter
    - BOD, TOC, Organic mater, pesticides, hydrocarbons, PAH (Polycyclic aromatic hydrocarbons)
- Metals
    - Cooper, cadmium, lead, zinc, arsenic, chromium
- Biological
    - Total coliform, *e.coli*, enterococci,

In this scenario, as a river (view in a fixed point) is a dynamic and medium speed variation water body, one data value every 15 minutes of measures is enough. This value may be an average value, if the sensor gives a "continuous" value, or a discrete value, if it is the result of an analytical process.

Actually, samples to measure are taken every 30-70 Km along the river, and usually near the river bank because of maintenance cost. But if there are existing infrastructures as bridges, samples can be taken from the middle of the river.

A more dense grid along and across the river may be interesting when spill is detected to determine the exact origin of the problem, but may be very expensive to have always working, so a solution can be a mobile navigating system above the river from the fixed station that detects the spillage.

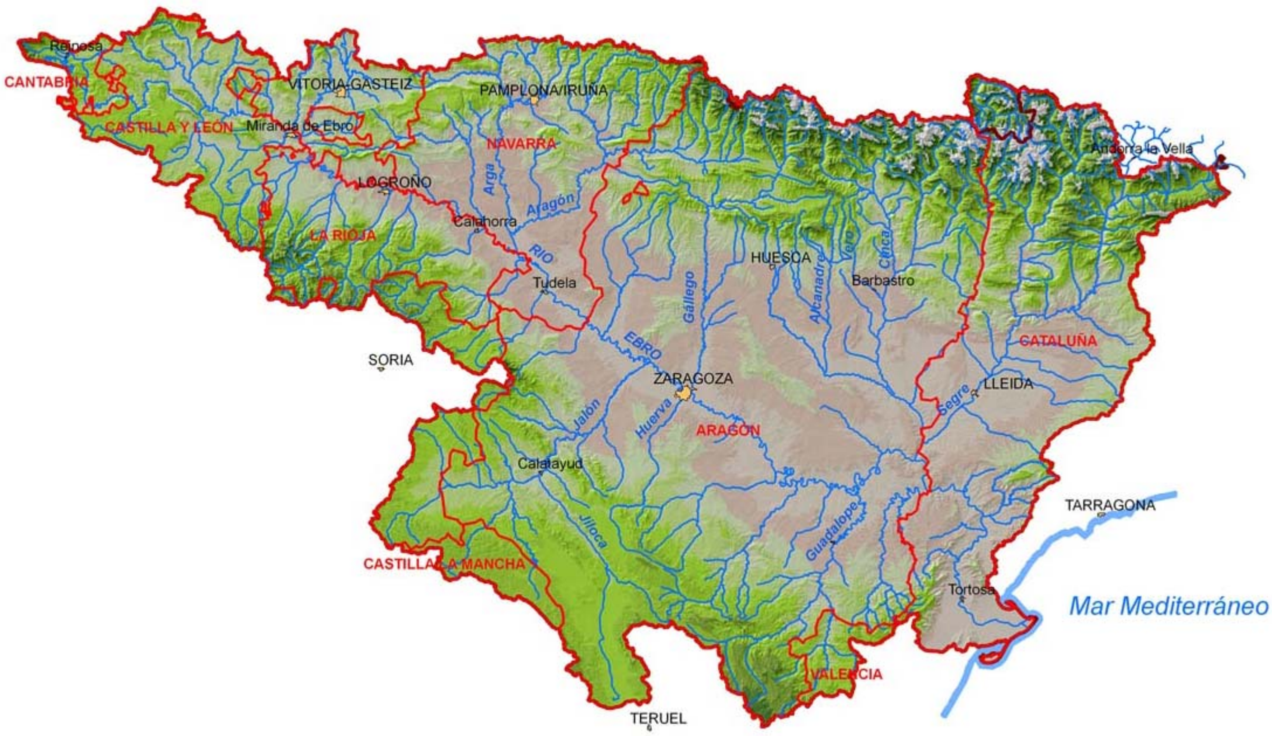


Figure 3: The Ebro basin

In the river scenario, the vertical profile is also necessary near the mouth of the river for detection of saline intrusion. In the Ebro basin, this is interesting at the river's delta

Figure 4: Points of measure of saline intrusion in the Ebro's Delta

4 The System Requirements

The objective of MOBESENS is to provide a modular and scalable ICT based solution for water quality monitoring that enables data to be gathered quickly and reported across wide areas.

The objective of this chapter is to define the list of requirements of the different parts of the MOBESENS system in order to obtain the global solution to solve problems of the three selected scenarios.

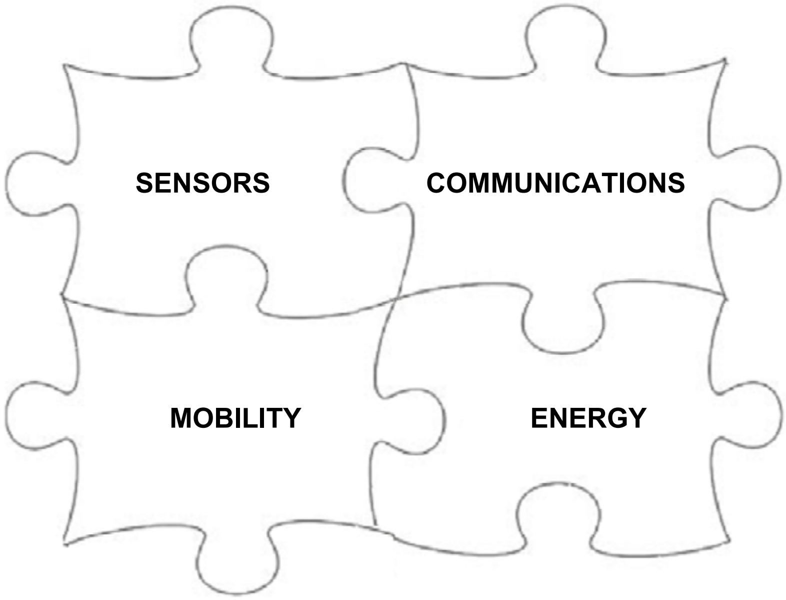


Figure 5: Puzzle to resolve in MOBESENS

In order to fit together the 4 main parts of the puzzle (sensors, communications, mobility and energy), every part of the puzzle is related to the others parts and the requirements must be know:

- How much energy needs a specific sensor, or probe coupling several sensors, to make a measure.
- How much energy needs a communication system to send a byte.
- How many bytes must send a sensor to have information.
- How much energy the mobility system needs to make a displacement.
- How much information must be sent to control de mobility system.

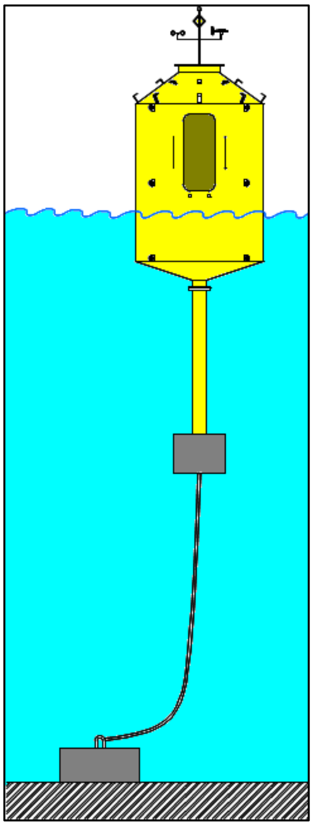
4.1 Performance Requirements

The objective of MOBESENS is to provide a modular and scalable ICT based solution for water quality monitoring that enables data to be gathered quickly and reported across wide areas. The solution includes:

- Mobile elements which are capable of navigation, facilitating operation, even in bad weather, and enabling a rapid relative localization and tracking (e.g. of contaminants).
- Capability of both surface and subsurface measurements enabling 3D.
- Low power wireless sensors network that gathers measured data samples with timestamp and location information. This data samples will be entered automatically into the information system to facilitate analysis and issue alarms.

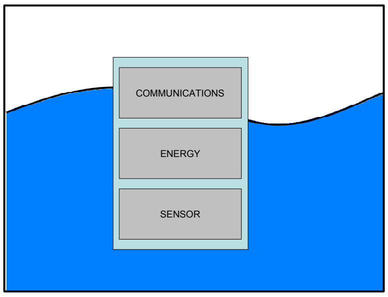
4.1.1 Surface Mobility

From the surface mobility point of view, three types of elements must be solved in the MOBESENS project:

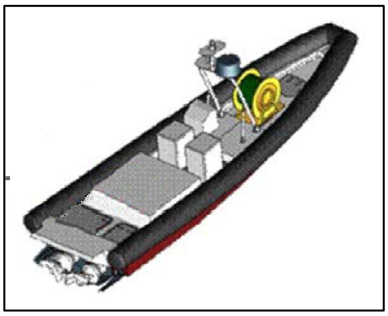


- Buoys. Are measuring point in a fixed position. The principal characteristics buoys must provide are:
    - Include the measure and communications elements with its energy supply.
    - Communication and sensor must be low power components, so renewable energy supply elements (inertial micro generators, fluid flow …) could be used.
    - The measure system integrated in the buoy includes all elements needed to make the measure (pumps, valves, reactants …) and all elements needed to ensure the correct measure during the defined productivity cycle (autocalibration, cleaning system …)
    - The communication system must be able to work in autonomous way, recognising itself in the network and detecting the best way for arriving its information to the Main Receiver.
    - The size of buoys will depend of elements included inside: could be in a small package (40 cm high x 10 cm Ø) if only includes a few sensors and communications system, or big if includes a profiler system with its energy provider.

- Drifters. Are measuring point in a mobile position, but without capability of controlled navigation. Drifter includes the measure and communications elements with its energy supply. Must be a low cost element, and communication and sensor must be low power components, so renewable energy supply elements (inertial micro generators, fluid flow …) could be used. As Drifter is autonomous, the measure element integrated in the LPA must include the sensor, all elements needed to make the measure (pumps, valves, reactants …) and all elements needed to ensure the correct measure during the defined productivity cycle (autocalibration, cleaning system …)



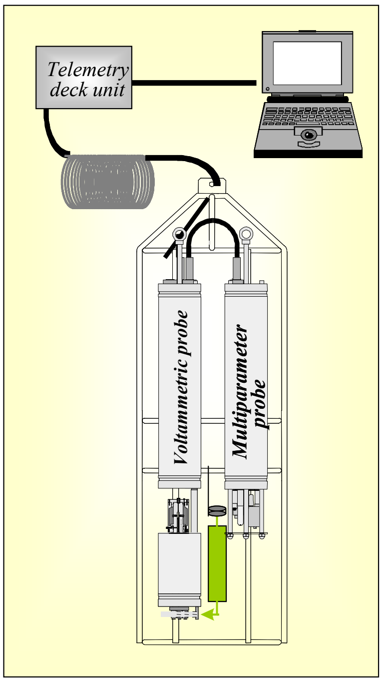
- Boats or USV (Unmanned Surface Vehicle). The term USV refers to any vehicle that operates on the surface of the water without a crew.
  USV includes the navigation, measure and communications elements with its energy supply. As Drifter is autonomous, the measure element integrated in the LPA must include the sensor, all elements needed to make the measure (pumps, valves, reactants …) and all elements needed to ensure the correct measure during the defined productivity cycle (autocalibration, cleaning system …)
  The principal functionalities the USV must provide are:
  - Navigation. The USV has to be able to navigate from A point to B point in an autonomous way
  - Communications. The USV must be able to communicate with the network of sensors and with the Control Centre.
  - Energy management
  - Payload



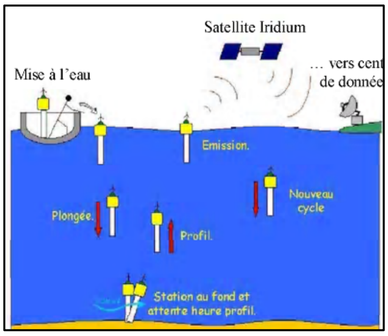
4.1.2 Subsurface Mobility

From the vertical mobility point of view, two elements must be solved in the MOBESENS project:

- The In situ Profiling System (ISP). Is a mobile element for making the subsurface measurements so vertical profile measurement of parameters could be done down to 500m depth. In order to make the measure at different points, the system must be connected to an automatic winch system.
  The profiling system must allows simultaneous measurements of master variables (pressure, temperature, pH, dissolved oxygen, conductivity, salinity) and of the dynamic fraction (i.e. the maximum fraction of metal potentially available) of Cu, Pb, Cd and Zn.
  The ISP could be installed in:
  - A fixed buoy. The vertical profiles will be obtained always in the same point.
  - A USV. Moving along a lake, sea or river, and stopping at a know position, IPS can go down to perfoem water for making subsurface measurement.



- The Autonomous Profiler System. It is an autonomous system of measurement, in situ in coastal areas (depth < 400m) able to provide regular, without external intervention, profiles (pressure, temperature, salinity and other relevant parameters such as oxygen, turbidity and fluorescence) of the water column at the point of deployment. This system is recoverable and the span of life should be 320 dives at 200m.



4.1.3 Temporal and spatial data availability

With the scenarios mention in *Chapter 3 Scenarios*, the temporal and spatial data availability for the measurements depends of the scenario and the working conditions. For each one the minimum and maximum useful value are given

In the MOBESENS project, to working conditions for the alert system are defined: Normal operation and Special Operation:

- Normal operation System
  - Lake System
    - Surface values — Temporal grid: 15 minutes. Horizontal grid: 100 – 5.000 m
    - Subsurface values — Profile: every 6 hours. Vertical grid: 1 – 2 m
  - Coastal
    - Surface values — Temporal grid: 30 minutes. Horizontal grid: 100 – 5.000 m
    - Subsurface values — Profile: every 6 hours. Vertical grid: 1 – 5m
  - River
    - Surface values — Temporal grid: 15 minutes. Horizontal grid: 500 – 10.000 m
    - Subsurface values — Profile: every 6 hours. Vertical grid: 0.5 – 2m
- Special Operation Modem (under demand of operator or in case of some specific alerts)
  - Lake System
    - Surface values — Temporal grid: 0.5 – 30 minutes. Horizontal grid: 20 - 500 m
    - Subsurface values — Profile: every hour. Vertical grid: 0.5 – 1m
  - Coastal
    - Surface values — Temporal grid: 1 minutes. Horizontal grid: 20 - 500 m
    - Subsurface values — Profile: every 6 hours. Vertical grid: 0.5 – 3m
  - River
    - Surface values — Temporal grid: 0.5 minutes. Horizontal grid: 50 – 1.000 m
    - Subsurface values — Profile: every hour. Vertical grid: 0.5 – 1m

4.1.4 Communications structure

MOBESENS solution includes low power wireless sensors network that gathers measured data samples with timestamp and location information.

Network has two different elements: the nodes and the gateway. System works in autonomous way, recognising itself in the network and detecting the best way of sending its information to the gateway.

- When building a network, the node searches the nearby elements, identifying its positions form the Main Receiver.
- When as some information, sends it to the nearby element that is closer to the Main.
- When receiving a message, determines if is form the main (comes form an element distant from the gateway), acting then as a repeater, and sending the message to the next element that is closer to the main. If the message comes from the Main, sends it the nearby elements that are more distant from the Main.

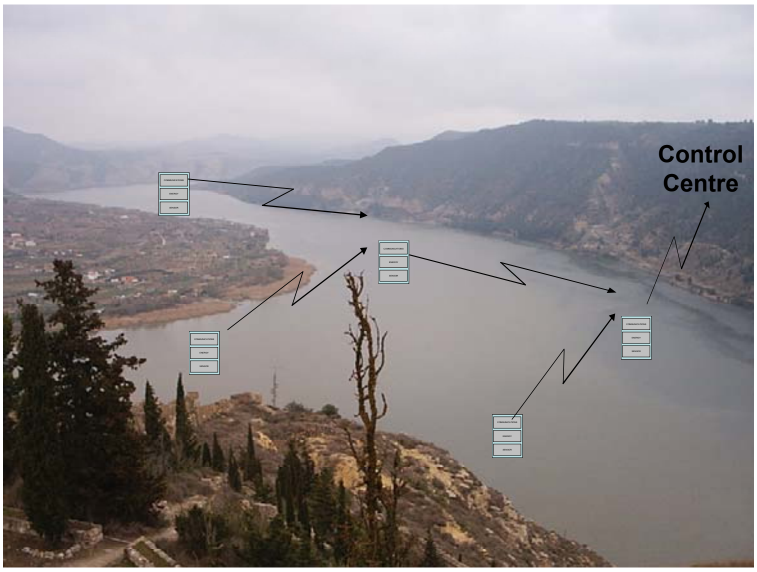


Figure 6: Sensors Communication Structure

4.1.5 Control Centre Data Validation & Representation

In a Control System, three layers are defined:

- Remote Stations, in charge of the physical measure of the elements.
- Communication System, in charge of transport data from remote station to information system.
- Information System, in charge of data storage, validation and processing. Data provided by sensors arrives, by means of communication network, to the acquisition system. This system, useful for corrective maintenance, is not usually prepared to store data with a valid qualification, or a quality qualification.

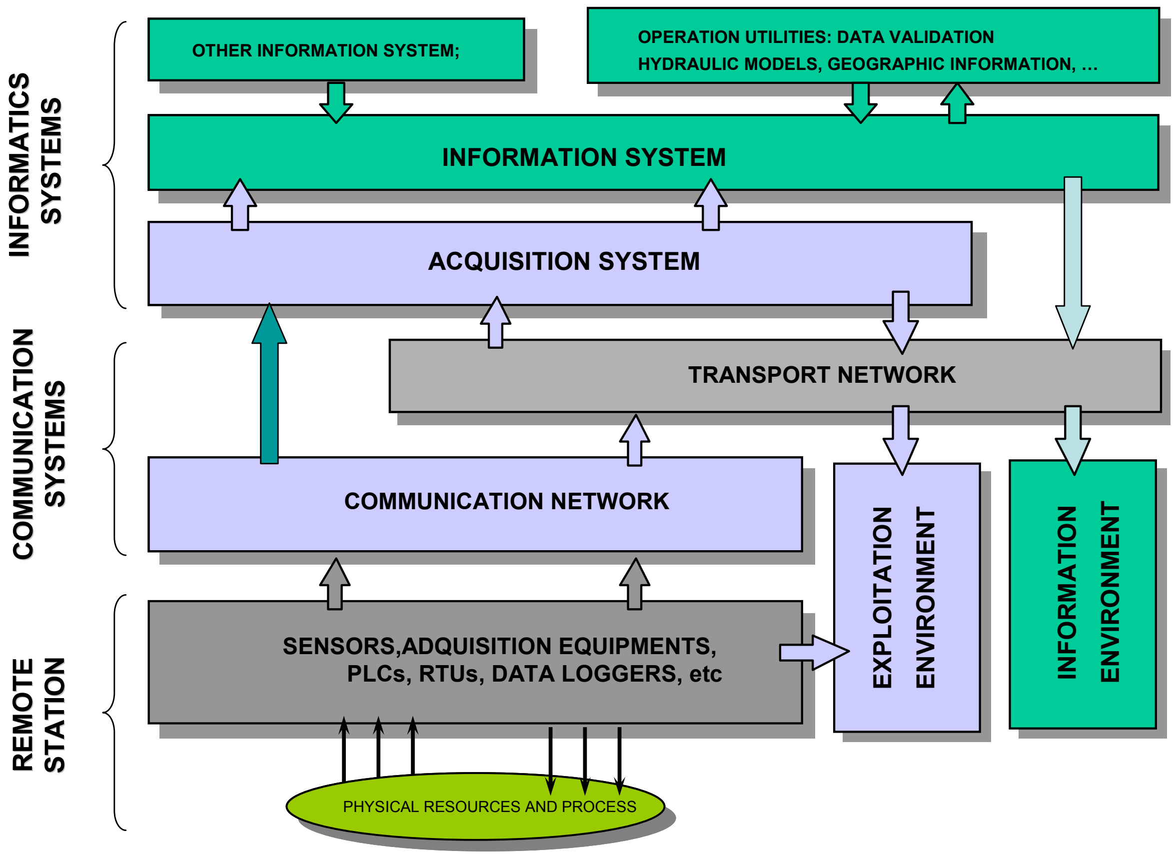


Figure 7: Control Systems and Information Systems

In the Information System, to allow system a flexible structure that covers needs for data exploitation (representation and processing), it is necessary to structure the data base in two levels:

- Raw Data. Data provided by the acquisition system, with automatic insertion mechanism with data validation. Great amount of data, that remains only for a period of time (months).
- Consolidate Data. Summarize data (hourly, daily …), with no holes and reliability information of data quality. The amount of data is manageable, and remains always.

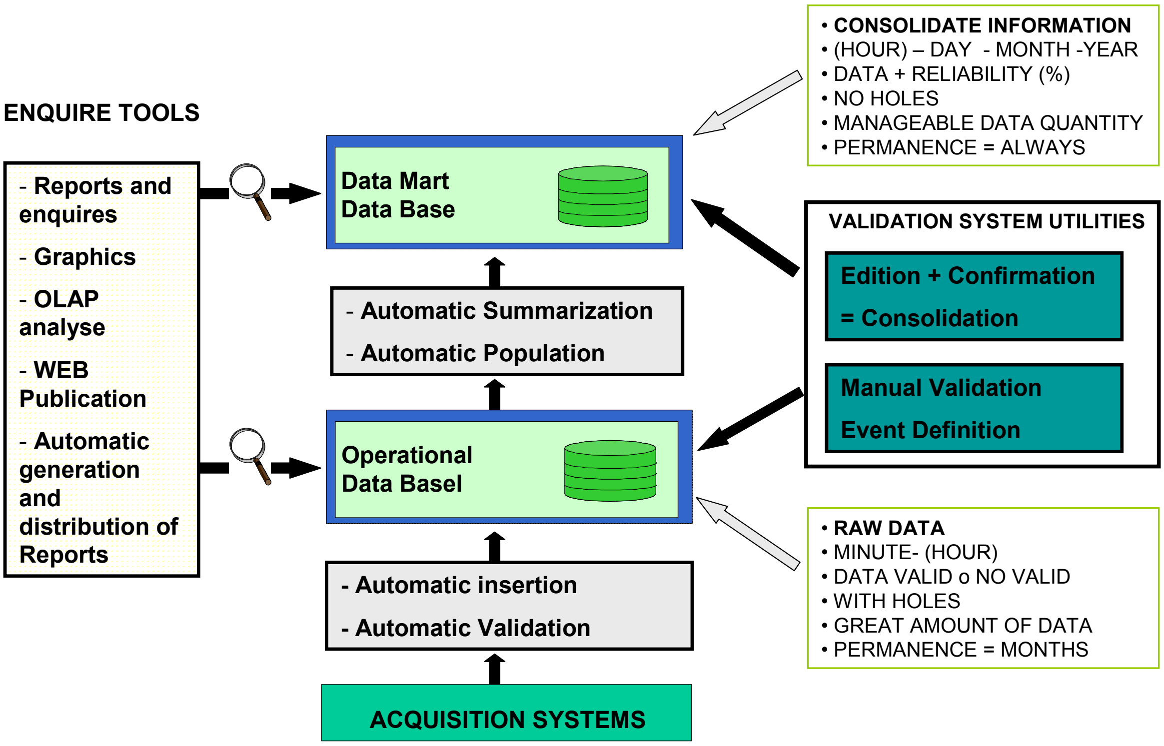


Figure 8: Information System Structure

Validation is defined as marking of data provided by sensors in operational DB as valid or invalid. The Validation System is a group of Data Base structures, automatic process and management utilities that allow the Data Administrator guarantee the quality of information to the final users.

There are different validation types:

- By means of automatic process. Automatic process may be:
  - Validation by range and/ or slope. Only values in a predefined range, and with a slope (difference from previous value, with time consideration) inferior to the selected, are considered correct.
  - Automatic hole filling and data synchronisation. When there is a mistake in a sensors or communications, and in the historical sequence of data is found a lack of values, automatic hole filling allow to generate "virtual" values.
  - Multivariable validation.
    - Cross-validation. Validation of data by comparing 2 measures of the same station.
    - Geographic validation. Validation of data by comparing the same measure of different stations, knowing the space influence in measure.
    - Geographic and time. Validation of data by comparing the same measure of different stations, knowing the time influence in the measure, like in the rivers.
  - Historical data validation. Validation of data by comparing it with the historical values
- By direct action of the administrator of data (manual validation). Validation System must provide easy utilities as:
  - Graphical data visualization, including validated data, not validated data, data pending of validation and events.

- Data edition, allowing marking data as validated or not, and given data a reliability value.

4.2 Measure Requirements

The objective of this chapter is to define the list of measure the MOBESENS project has to be able to support, taking in account the interesting parameters mention in *Chapter 3 Scenarios*.

A table with the desired characteristics of range, precision, accuracy and production time is made. Also, tables with different types of available sensors with the energy, communication, and additional elements required are provided.

Temporal and Spatial data availability for measurements is define in *Chapter 4.1 Performance Requirements*

Table 3: Measurement requirements for MOBESENS System

PARAMETER		CHARACTERISTICS	
NAME	**UNITS**	**RANGE**	**ACCURACY**
Temperature	ºC	0 / 50	1% or ± 0.1 ºC
pH	udpH	0 / 14	± 0.1 udpH
RedOx	mV	-1000 / 1000	10 mV
Conductivity Lakes	µS/cm	0/10.000	5%
Conductivity sea	mS/cm	0/100.0	5%
Dissolved O2	mg/l O2 or ppm	0 / 20	10% or ± 0.2 mg/l
Turbidity	NTU	0 / 500	5%
Pressure	dbar	0 / 500	0.05 % full scale
Na^{+}	mg/L	20 / 500	10%
K^{+}	mg/L	2 / 150	10%
Ca^{2+}	mg/L	10 / 500	10%
Mg^{2+}	mg/L	5 / 300	10%
NH_4^{+}	mg/L	0.1 / 10	10%
NO_3^{-}	mg/L	10 / 300	10%
SO_4^{3-}	mg/L	50 / 1000	10%
Cl^{-}	mg/L	20 / 500	10%
Cu :	mg/L	0.5 / 20	10%
Pb :	µg/L	2.5 / 200	10%
Cd :	µg/L	1 / 50	10%
Zn :	mg/L	0.1 / 5	10%
PAH :	µg/L	0.05 / 2	10%
Phenols	µg/L	0.1 / 5	10%

Table 4: Characteristic of Temperature sensors

TECHNOLOGY	RANGE	ACCURACY	OUTPUT	PRODUCTIVITY CYCLE		COMMENTS
PT100	-50 / 200	± 0.05 ºC	Resistance	> 6 month		100 Ω + 38,5 Ω/ºC
PT1000	-50 / 200	± 0.05 ºC	Resistance	> 6 month		1000 Ω + 385 Ω/ºC
K Thermocoupler	-200 / 1.350 ºC	± 1.5 ºC	41 µV/°C	> 6 month		More range than PT100, less precision
T Thermocoupler	-200 / 350 ºC	± 1.5 ºC	43 µV/°C	> 6 month		More range than PT100, less precision

Table 5: Characteristic of pH sensors

TECHNOLOGY	RANGE	ACCURACY	OUTPUT	PRODUCTIVITY CYCLE		COMMENTS
Glass Electrode + Adapter	0 / 14	± 0.05 udpH	-700..+700 mV	1 month		Needs a cleaning system. With auto-calibration system the PD can increase

Table 6: Characteristic of RedOx sensors

TECHNOLOGY	RANGE	ACCURACY	OUTPUT	PRODUCTIVITY CYCLE		COMMENTS
Glass Electrode + Adapter	-1000 / 1000	5 mV	-1..+1 V DC	1 month		Needs a cleaning system. With auto-calibration system the PD can increase

Table 7: Characteristic of Disolved Oxigen sensors

TECHNOLOGY	RANGE	ACCURACY	OUTPUT	PRODUCTIVITY CYCLE		COMMENTS
Polarografic / Galvanometric	0 / 20	10% or ± 0.2 mg/l		1 week..1 month		Needs a cleaning system
LDO prove	**0 / 20**	**0.1 mg/l**	RS232 / 4..20 mA	12 moth		Very robust system. Life depends of nº measures

Table 8: Characteristic of ChemFet sensors

PARAMETER		CHARACTERISTICS				
NAME	**UNITS**	**RANGE**	**ACCURACY**	**PRECISION**	**Time const.**	**TYPE**
Ca^{++}	mMol	0.3 – 20 mM	< 2.5 mM			
NH_4^+	mMol	0.05- 1 mM	0.025 mM			
NO_3^-	mMol	0.5- 5mM	0.5 mMol			

SENSOR	ENERGY REQUIREMENTS					
TECHNOLOGY	**SUPPLY**	**CONSUMPTION**	**OUTPUT**	**PRODUCTIVITY CYCLE**		**COMMENTS**
ChemFET	5_- 9V DC	0.1 mA	-2V to 0 V			

Figure 9: Characteristic for OCEAN Seven 316Plus probe (Idronaut) which can be controlled by the VIP voltammetric probe or be used individually

PARAMETER		CHARACTERISTICS				
NAME	**UNITS**	**RANGE**	**ACCURACY**	**Resolution**	**Time const.**	**TYPE**
Pressure Temperature Conductivity Dissolved O2 pH	dbar °C mS/cm ppm and % sat udpH	0 / 500 -3/+50 0/70 0/50 and 0/500% 0/14	0.05 % fill scale 0.003 0.003 0.1 ppm/1% 0.01	0.002 % full scale 0.0002 0.00025 0.01 ppm/0.1% 0.001	50 ms 50 ms 50 ms 3 s 3 s	

Probe	ENERGY REQUIREMENTS					
TECHNOLOGY	**SUPPLY**	**CONSUMPTION**	**OUTPUT (various options)**	**Internal non-volatile data memory**		**COMMENTS**
	9….18 V DC	150mA @ 12V (running) 0.8 mA @ 12V (sleep)	RS232/RS422/FSK telemetry/Wireless Bluetooth	1 Gbyte		Internal battery pack available

Figure 10: Characteristic for Mini-Logger CTD O2 probe (Idronaut).

PARAMETER		**CHARACTERISTICS**				
NAME	**UNITS**	**RANGE**	**ACCURACY**	**Resolution**	**Time const.**	**TYPE**
Pressure Temperature Conductivity - Salt water - sea water Dissolved O2	dbar °C mS/cm µS/cm ppm and % sat	0 / 500 -3/+35 0/70 0/7000 0/50 and 0/500%	0.05 % fill scale 0.005 0.007 5 0.2 ppm/1%	0.0015 % full scale 0.0006 0.001 0.1 0.02 ppm/0.1%	50 ms 50 ms 50 ms 50 ms 3 s	

Probe	**ENERGY REQUIREMENTS**					
TECHNOLOGY	**SUPPLY**	**CONSUMPTION**	**OUTPUT (various options)**	**Internal non-volatile data memory**		**COMMENTS**
	4.5….11 V DC	23 mA @ 9V (running) 110µA @ 9V (sleep)	RS232/RS422/ Asynchronous TTL(0.5VDC)/ Bluetooth	128 Mbytes		Internal battery pack available

Figure 11: Characteristic for VIP voltammetric probe (Idronaut) . (**Probe available**)

PARAMETER		CHARACTERISTICS				
NAME	**UNITS**	**RANGE**	**ACCURACY**	**Resolution**	**Time const.**	**TYPE**
Dynamic fraction of metals: Cu : 5 min preconc. t 15min preconc. t Pb : 5 min preconc. t 15min preconc. t Cd : 5 min preconc. t 15min preconc. t Zn : 5 min preconc. t 15min preconc. T	 nM nM nM nM nM nM nM NM	 3-150 0.3-30 0.15 – 150 0.03-30 0.3-200 0.05-40 3 – 150 0.4 - 30	≤ 7% (4 Me)	12 % (sensor to sensor/day to day meas.) (4 Me)		GIME sensor (4 Me)

Probe	ENERGY REQUIREMENTS					
TECHNOLOGY	**SUPPLY**	**CONSUMPTION**	**OUTPUT**	**Internal non-volatile data**		**COMMENTS**
	10….30 V DC	150mA @ 12V (pump off) 200mA @ 12V (pump on) 0.8 @ 12V (sleep)	RS232/telemetry	128 Mbytes		

4.3 Communications and Mobility Requirements

The objective of this chapter is to define the communications requirements that MOBESENS project has to be able to support, taking in account functionalities given in *Chapter 4.1 Performance Requirements* for the three scenarios mention in *Chapter 3 Scenarios*

Also, different tables of communications systems the MOBESENS project can use are provided.

4.3.1 Wireless nodes communications.

For the communications between nodes, the requirements are in Table 9

Table 9: Wireless node Communication parameters

Parameter	Unit	Required value
Communication type		Full Duplex capability
Dynamic reconfiguration		Yes. Network must support the adding or elimination of a node dynamically
Adaptive routing		Yes. Network must determinate the best way between the node to send the information
Data rate	bit/s	1 k – 100 k
Bit Error Rate (BER)	%	1-5
Packet Error rate	%	1-10
Range	m	10-100
return time	S	< 1s
response time	S	< 1s
Power supply	mW	< 10 mW
Information supported		Measured values information, with position and time stamp. The maximum number of different types of measures is defined as 255. Status information. Information of status of the different elements of sensors Command Information. Orders from the Control Centre or other element of the grid, such as change of position, change of sample time, …

Table 10: Communications Requirements for GSM

SYSTEM		CHARACTERISTICS		
NAME		BAUD RATE	TRANSMISSION	COVERAGE
GSM		9600	Direct (must "call" Control Center)	Good (All EC) Distance to base station < 20 Km Distance to Control Centre >> 1000 Km

EQUIPMENT	ENERGY REQUIREMENTS						
TECHNOLOGY	SUPPLY	POWER OFF	SLEEP	IDLE	TRANSMISSION	CONNECTION	COMMENTS
GR64	3.6 V	< 0.1 mA	1.6 mA	27 mA	2050 mA	RS232	
TC35i	4.2 V	50 uA	3 mA	15 mA	300 mA	RS232	

Table 11: Communications Requirements for GPRS

SYSTEM		CHARACTERISTICS		
NAME		TRANSMISSION RATE	TRANSMISSION	COVERAGE
GPRS			Packet Data (IP)	Good (All EC) Distance to base station < 20 Km Distance to Control Centre >> 1000 Km

EQUIPMENT	ENERGY REQUIREMENTS						
TECHNOLOGY	SUPPLY	POWER OFF	SLEEP	IDLE	TRANSMISSION	CONNECTION	COMMENTS
GR64	3.6 V	< 0.1 mA	1.6 mA	27 mA	2050 mA	RS232	Implements the TCP/IP stack with AT Commands

4.3.2 Measurement block communications

In the MOBESENS systems, sensors or proves (measurement block) are connected to the Wireless Node (communications block) by means of an interface (hardware and protocol) that has to fulfil several features:

- Needs to support different types of sensors (e.g. pH and voltametric sensor) simultaneously.
- Data exchange between block includes measurement data with time stamp (e.g. the measured pH value in 2 Bytes together with the corresponding timing information in 4 Bytes) ad commands (sample time configuration, sample order …).
- Data storage is required, even in the sensor and/or the wireless node.
- Low-power management and mutual wake-up.
- Clock synchronization.

The interface general specifications are:

- Hardware interface: A serial interface will be used in junction with several digital I/O lines (CHIP_SELECT or RS232_ENABLE signal to support multiple sensors).

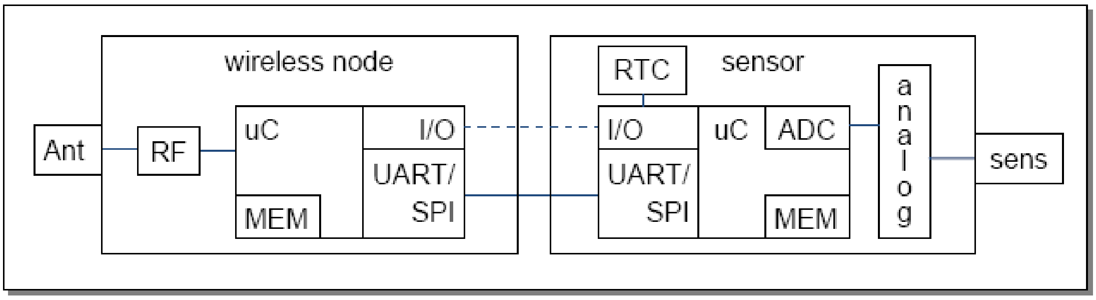


Figure 12: Interface of sensors to communications

- Protocol: A basic protocol based on the request-response principle will be used. In order to keep the data exchange simple, the interface will operate in a master-slave mode such that the wireless node (master) interrogates the sensor (slave). In this configuration the sensor does not initiate any communication and the wireless node retrieves all information via polling. Furthermore, the sensor remains in low-power (sleep) mode and would be woken up via the RS232 interface. If it is required that the sensor also initiates data transmission at any time by itself, e.g. for time-critical alarm events, this concept needs to be reviewed.
  An initial set of the required request messages that are sent from the master is given. The response messages would include the answer, e.g. sensor data, from the sensor or an indication if the action was successful.
  - IDENTIFY: identification including capability information (type of sensor, measurement quantities like pH, temperature, etc.)
  - STATUS: status including battery voltage and/or power, calibration state, etc.
  - GET_PARAM: set sensor parameters like e.g. sampling frequency
  - SET_PARAM: get sensor parameters like e.g. sensor measurement range, calibration parameters as well as all parameters than can be set (see message above)

- START_MEASURE: start measurement based on current measurement parameters
- GET_DATA: obtain data values available so far, e.g. all data values stored in sensor data buffer
- ALARM: obtain alarm information

4.3.3 Mobility requirements

In the MOBESENS system, a distinction must be made between system-level mobility and physical mobility, as the tracking of the physical position of the node and its speed is necessary:

- System-level mobility refers to the movement of node from a cluster to another.
- Physical mobility refers to the movement of a node inside the same cluster.

Also, the mobility can be active when the node is guided from one position to another. It is passive when the movement takes place by the influence of physical phenomena such as the movement of waves.

From a technical point of view, the mobility parameters are often related to the position (including the z component), the speed, the acceleration, the attitude, etc. Attributes of these characteristics are precision, resolution, consistency and replicability, etc.

Uncertainty about localization and orientation of the nodes is an important parameter in the mobility process. These parameters have to be defined since geographic clustering requires knowledge of the position and the speed of nodes.

It is also important to distinguish between the real-time nature of the physical mobility and the less updating time requirements of the system-level mobility. A suitable solution is to handle the system-level mobility in the framework of an off line positioning process and to keep track in an on line positioning process of the location, the orientation and the speed of the nodes inside the same cluster.

4.3.4 Localisation requirements

Localisation of nodes taking part in the Mobesens system will have a big impact on the quality and the availability of the measurements. Two types of localisation have to be distinguished:

- Absolute localisation where the position can be reported on a map
- Relative localisation where what is important is "how one element is spread in relation to the others"

If the first value is important in Mobesens to ensure an efficient tagging of each data collected and should be completed by the depth value for sub-surface measurements, the second will need to coexist. Indeed, this is the quantity that will be used to optimize efficiency of the cloud of nodes locally. Communication will probably benefit from this local knowledge by adding to the link neighbourhood a notion of position closeness. Another idea is to use this relative localisation to enhance surface mobility capabilities at a lower cost than having to use absolute localisation.

Obviously, relative localisation could be replaced by absolute localisation. More over, the position quality of the absolute localisation will probably be better than the relative one. Never the less, relative position has its advantage in terms of autonomy of the system (if connectivity to the information system is lost for some time) as well as in terms of power consumption since the idea is to use the radio link.

Its characteristics (precision, delay and period) will also be a key element to ensure proper surface mobility.

4.4 Energy Requirements

Four main methods of harvesting electrical power for the MOBESENS nodes have initially been identified. These are:

- Solar power
- Micro-turbine (tethered sensors or craft mounted for generation with water or air)
- Inertial devices
- Buoyancy based generation (tethered sensors)

Here, the basic expected practical limits on the amount of power density will be discussed for each of these methods in order to identify the most promising energy sources for different scenarios and to determine the potential limitations of the functionality of MOBESENS nodes which rely on harvested energy for their power. The power supply either forces requirements on the rest of the system because only a limited amount of power may be available for the volume allocated to the supply, or, conversely, if a given amount of power is required, then the power supply sets requirements on the system in terms of volume required. This part of the report establishes the limits on power and volume so that the trade off between power generated and allowed volume of the energy harvester may be investigated.

In many energy harvesting scenarios, the power density achievable is not constant with changing device size[B]. It is therefore not always straight forward to scale plots such that the power is readily calculated knowing a power density and an energy harvester volume. For this reason, the plots that follow show power plotted as a function of the length of one side of the energy harvesting generator, assuming either a harvester occupying an area with little volume, or a cubic volume. This length is called the characteristic length of the generator. For a solar cell and a turbine generator, the harvester will consume little volume, but the area is important and thus power is related to the square of the characteristic length. For inertial and buoyancy based devices, it is the device volume that is important when determining the power available from each device and thus power is related to the cube of the characteristic length. It is likely for typical MOBESENS installations that the size of the nodes have characteristic lengths between 1 and 10 cm.

4.4.1 Solar Power

Solar cells are a mature technology. The amount of power that can be harvested is directly proportional to the area of the cell used and on the amount of solar radiation reaching the cell. This is dependent on the cloud cover and distance from the equator. MOBESENS concentrates on monitoring lakes and rivers in Europe. Within Europe, typical amounts of solar energy flux that can be collected in a 24 hour period range between 1 kWh/m² (cloudy day north of the equator) and 8 kWh/m² (in clear weather closer to the equator). Typical solar cells can achieve around 15% efficiency in terms of conversion of solar flux into electrical energy and scale well to the sorts of sizes envisaged for MOBESENS nodes. Power processing of the energy from solar cells into a useful form is well investigated and can achieve high levels of efficiency, at over 80%. Therefore, it is very likely that the end to end efficiency from solar collection to processed electrical power for a MOBESENS solar installation would be of the order of 12%. The plot below shows the bounds of the expected predicated power from such an installation.

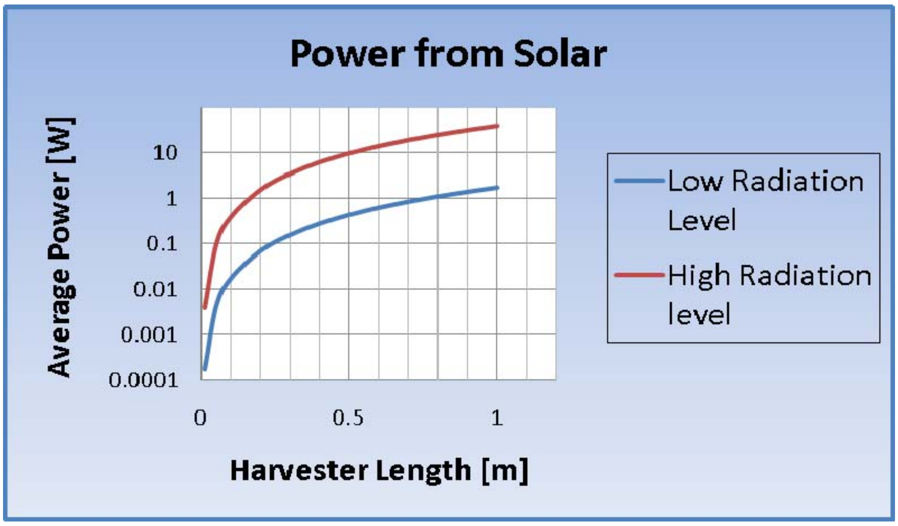


Figure 13: Power available from solar energy as a function of device size under two radiation levels

Solar could be a relatively attractive method of harvesting energy for MOBESENS nodes that have access to light due to the high reliability of solar devices. A harvester with a characteristic length of 10 cm (i.e. a device occupying an area of 100 cm^2) could be realistically capable of generating an average power of 0.5 W over a 24 hour period. So, a device with a characteristic length of 1cm (area of 1 cm^2) could only generate an average power, at best, of 5 mW.

4.4.2 Micro Turbine

Imperial has already developed micro turbines for use in air flow[C]. Whilst their design is not optimised for use in water, our experience with them allows us to estimate the power that could realistically be achieved from such a unit. There are three fundamental modes of operation that can be considered for a micro turbine in MOBESENS. These are:

- Tethered turbine which harvests energy from fluid flow in the river or lake
- Turbine which harvests energy from air flow
- A turbine generator on a sensor mounted on the hull of a moving craft

The basic expression for power output from a flow turbine is given as:

$$P = \frac{1}{2}\rho A V^3 C_p$$

Where ρ is the density of the fluid, A is the swept area of the turbine, V is the velocity of the flow and C_p is the efficiency, which for small turbines typically alters between 0.1 and 0.2.

Consequently, the following plots have been obtained showing power available at different flow rate scenarios for three different sizes of generator.

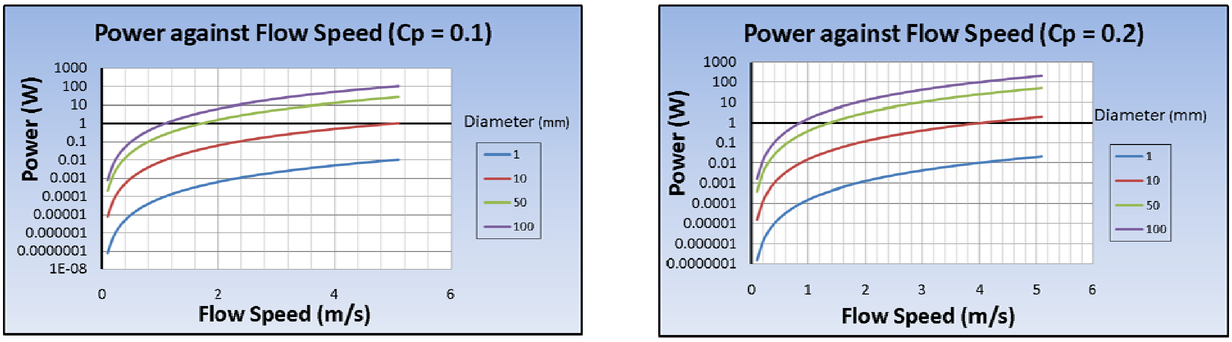


Figure 14: Performance of turbines with varying flow rates (in water)

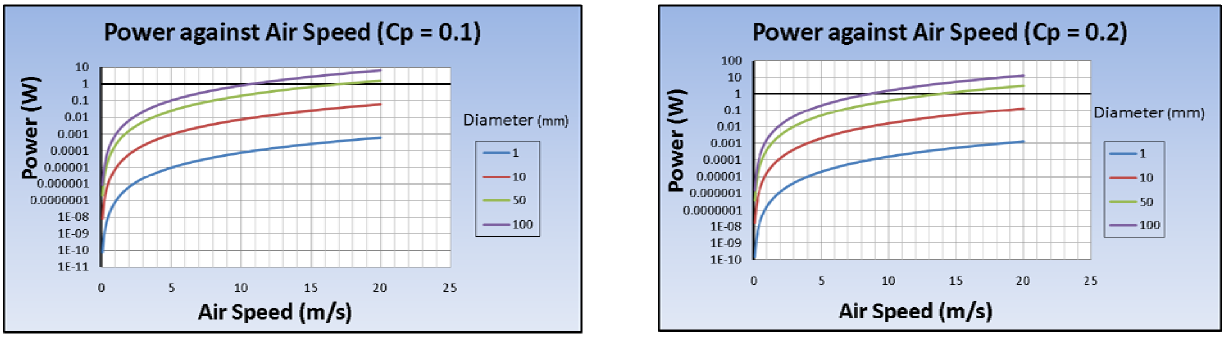


Figure 15: Performance of turbines with varying flow rates (in air)

When generating power from water flow, the two envisaged methods of harvesting are from tethered harvesters sitting in moving water or harvesters stuck to the hulls of moving craft. Running water in rivers may typically have speeds of almost zero up to 3m/s, whilst moving craft may travel at closer to 5m/s.
As can be seen, devices with characteristic lengths of 1cm can generate an average power of around 0.2 to 0.5 W for flow rates of 3 m/s in water depending on the efficiency. A device with a characteristic length of 10 cm could generate up to 50 W.
Air flows from a miniature wind turbine could be anywhere between zero and 15 m/s. At a typical 10 m/s, a turbine with a characteristic length of 1 cm could generate around 20 to 40 mW depending on efficiency and a turbine of characteristic length of 10 cm could generate between 5 and 10 W.

4.4.3 Inertial Devices

A significant advantage of inertial generators is that they form completely sealed units, and, unlike solar cells and turbines they are not susceptible to poor operation due to the formation of dirt or algae. The basic expression for the power output of an inertial micro generator is given by:

$$P = \frac{1}{2} Y_0 Z_l \omega^3 m$$

Where Y_0 and ω is the amplitude and frequency of the vibration source, m is the size of the proof mass, and Z_l is the allowed travel distance of the proof mass. Thus, for a characteristic generator length, optimal values of m and Z_l can be chosen.
The following graph has been plotted for 4 different sizes of generator as a function of wave amplitude. Typical wave frequencies are around 0.1 Hz [D] and so this is assumed in the following plot.

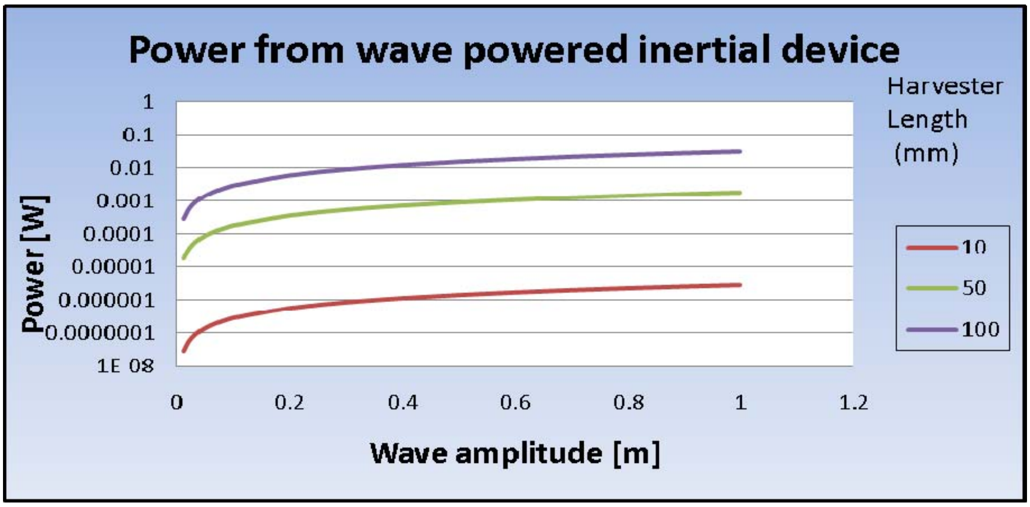


Figure 16: Power available for sealed inertial generator for various device sizes as a function of wave height

As can be seen, a generator with a characteristic length of 1 cm can generate around 1 μW with a wave amplitude of 0.5 m; a device with a characteristic length of 10 cm could generate around 10 mW under the same circumstances.

It seems, therefore, that inertial based harvesters are relatively unattractive as an approach to power generation for MOBESENS. This is mainly due to the low frequency of wave motion and the strong dependence of output power of an inertial device to frequency.

4.4.4 Buoyancy based generation

Devices which are tethered to the floor of the water mass could generate electrical power by using their buoyancy (and thus the varying position of a floating device on an uneven water surface) to do work against a fixed transducer tethered in a fixed position above the ocean floor. The amount of power that could be generated in this scenario is given by:

$$P = \frac{8}{3}\Pi r^3 \rho g Y_0 f$$

Where r is the radius of the device, ρ is the density of water, g is the gravitational constant, f is the frequency of the waves and Y_0 is the amplitude of the waves.

The following plot has been generated in order to show how much power can be obtained for this scenario. Again, it is assumed that the frequency of the waves is 0.1 Hz.

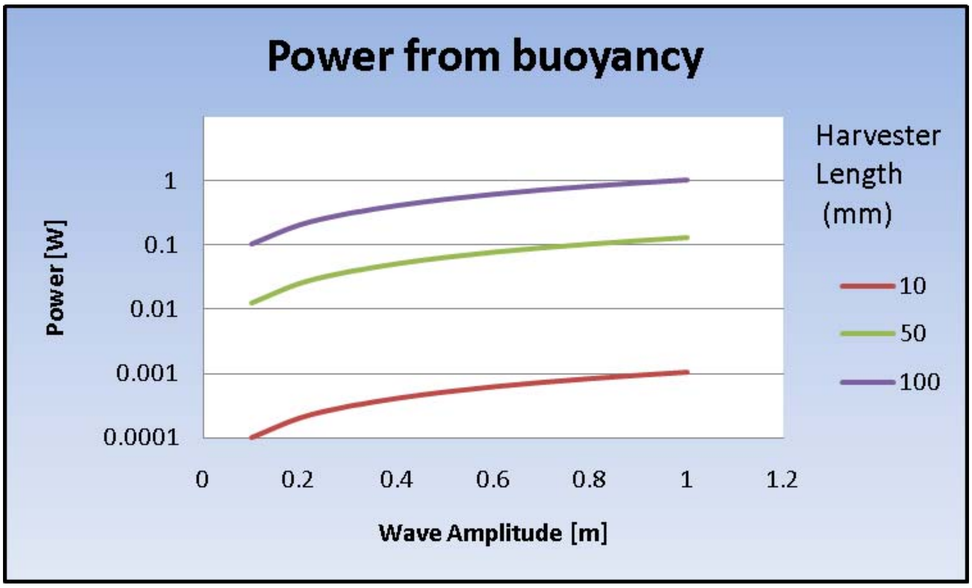


Figure 17: Power available from generation from buoyancy

As can be seen, a device of characteristic length of 1 cm could generate between 100 μW and 1 mW, depending on wave height, and a 10 cm device could be expected to generate between 100 mW and 1 W, depending on wave conditions.

4.4.5 Conclusions for Energy harvesting

As can be seen from the initial calculations, the amount of energy that can be harvested is highly dependent on the size of the MOBESENS nodes and this will significantly effect the functionality of those nodes. Some general conclusions can be drawn:

- It is unlikely that inertial based harvesting from the motion of the waves will ever be the best solution for MOBESENS. This is mainly due to the low frequency of wave motions.
- Solar power devices could be expected to generate around 5 mW for a characteristic length of 1 cm and 0.5 W for a characteristic length of 10 cm
- Turbines could be expected to generate of the order of 0.2 W for a characteristic length of 1 cm and 50 W for a characteristic length of 10 cm in water and around in air.
- Buoyancy based devices could be expected to generate in the order of 1 mW for a 1 cm device and up to 1 W for a 10 cm device.

Thus, turbines and buoyancy based devices are potentially the most sensible choices for motion based energy harvesting and solar when there is a requirement for no moving parts or a significant area can be dedicated to the use of solar cells.

4.5 Data processing requirements

The objective of this chapter is to define the list of data processing requirements that the MOBESENS project has to be able to support, taking in account the parameters mentioned in *Chapter 3 Scenarios*.

Data storage:

- System has to manage different types of data:
    - From sensors or probes: measures, alarms and evens or status.
    - To sensors or proves: actions (calibration, displacement, configuration …).

- Measurements will be tagged with a device of origin, a time stamp, a location of the measurement (absolute and/or relative) and a measurement type (in the form of a format and a description of the measurement or at least a pointer to a device, node or server holding the information).

- Measurement devices will be identified to ensure simple identification of the sensors or probes conducting the measurement, with a naming or identifier assignment system or authority. Also, due to the ad hoc nature of the system, devices must have characteristics for grouping within clusters of the nodes.

- System has to report sensors and measurements probes status in remaining battery lifetime, in recharging schedules and in availability.

Data processing:

- System will be provided with tools for anomaly detection (from the measurement data and the image or cartography built by the grid processing system) and identification of root cause for launching corrective actions (removal of rogue nodes, scheduling charging and replacement of measurement devices and nodes, correction of paths or trajectories and of positioning etc…)

- A knowledge base of sensors and probes used for the water quality measurements will be provided. This requires a description of the sensor or probe type and the measurements and calibration conditions for each probe. System will provide means to associate these parameters with each sensor or probe identifier (or identifier class) and conducted measurement

- Access system, sensors and probes must provide relative positioning and situation awareness (neighbouring nodes discovery and presence and own state information)

- System will be able to export data in other measurement for interoperability and compatibility, and as well as include measurements from other systems. This will be used to derive conversion and adaptation module requirements.

- System will provide tools for validation of data, as defined in *4.1.5 Control Centre Data Validation & Representation*.

Data visualization:

- Two profiles of user are defined:
    - Data Administrator. In charge of ensure data are available in operational data base for data user. Will have aces to alarms from sensors and devices, and tools for data insertion and validation.
    - Data User. In charge of data analysis.

- Query language for retrieval of measurements from the data base via the visualization interface will be used.

- In order to remotely program sensors and proves with parameter configuration and guidance control, system will provide an API.

- The MOBESENS system will, via its open interface, be compatible with all geographical information systems and measurement standards used by other water and environment monitoring systems.

- The MOBESENS system will be able to use all GIS and related coordinate systems transparently via an autonomous transcoding function just as easily as applications use MIME types to identify the characteristics of files and read them and visualize them using any tool in many current operating system

- The open interface will import and export time and location stamped measurements using all standard metrics and attributes and provide the means to convert and translate the measurements into the appropriate formats for importing and exporting purposes. This will facilitate cooperation at the European and global level.

- The MOBESENS system will to be able to integrate additional information and measurement from other systems, external probes, monitors and sensors. The system must consequently federate such information, store and provide on demand secure access to the collected and stored data for later analysis and management by end users.

- The MOBESENS system will be able to accumulate measurements, store history and ensure traceability and accountability of the measurements. The system should host and protect data concerning the measurements themselves in terms of:
    I. conditions of measurements, measurement systems specification, calibration status of probes and monitors and sensors
    II. source or authority requesting or launching the measurements
    III. devices and entities conducting or providing the measurements
    IV. measurement data should ideally be tagged with such attributes and augmented with reliability and estimation error information for each measurement

- The MOBESENS system will provide customized access to the grid system and the measurement data through user account creation according to established rights and privileges. Selective and customized access to data and 2D/3D rendering of the measured area, measurement points and values are required at the graphical user interface.

- The open interface will provide means for the selection of the desired target output format via the visualization interface

- The open interface will enable on line and on demand selection of formats and metrics of the collected measurements as well as the end user customized configuration of the visualization of the monitored area with ability to select all or a subset of the key parameters associated to each measurement point

- The interface will provide the means to create overlays for the visualization interface. The overlays can be visualized in isolation as well as in an aggregated way in a common overlay comprising multiple measurement layers and visualization levels (e.g. making visible or masking selectively measurement parameters).

- The MOBESENS System will also ease the interaction with other measurement analysis tools than its own to integrate results of data fusion and processing from external systems and should lump these into a common visualization and analysis framework and interface. Thus facilitating the creation of a common European space for environmental monitoring and management cooperation and collaboration.

5 Conclusion

The proposed implementation of MOBESENS provides a modular and scalable ICT based solution for water quality monitoring, and enables data to be gathered quickly and reported across wide areas.

The project has defined three different scenarios with the same objective (water quality monitoring for alert), but with different problems, dynamic behaviour and reaction time, interesting parameters to measure, place and situation to take the sample, and number and frequency of the measure:

- A still freshwater body
- Sea and coastal lagoon
- Rivers.

The proposed implementation of MOBESENS gives answers to specific problems in each scenario.

Requirements for the general system, sensors, communications and mobility, energy and data processing are defined. They are not static of definitive, as while project goes on will be precise.

6 Vocabulary

6.1 General

- USV: Unmanned Surface Vehicle.

- Sensor: Device that measures a physical quantity produced by a chemical or physical reaction and converts it into a signal which can be read by an observer or by an instrument.

- Analyser: Instrument or device which conducts chemical analysis (or similar analysis) on samples or sample streams. Such samples consist of some type of matter such as solid, liquid, or gas. The sensing elements of the analyser can be placed in a process vessel or stream of flowing material to conduct the analysis, or a sample may be taken from the process to the analyser.

6.2 Communication

- WSN: Wireless Sensor Network.

- Node: one element pertaining to and participating to the communication system; in this specific application, a node might reside in a buoy, a relay, a ground station, a gateway, etc. It might be mobile or fixed.

- Sink: this is the endpoint to which all nodes (pertaining to a given application) send their data. Several sinks can coexist in a network, so that data can be sent via shorter paths. Sinks usually also plays the role of gateway, so that the data collected at the sink can be made available to higher layers of the application for stporage, processing, decision-making, etc.

- RSSI: Received signal strength indicator: this local indicator gives the strength of the radio signal received from the node from which data has been received. This is a real-time measurement of the radio signal sensed at the radio front-end. The value can vary typically from 0 to 6, 0 to 255, etc. The actual interpretation of the absolute value is difficult and fuzzy. Sometimes, it is more valuable to look only at the variations of the RSSI.

- Range: the maximum distance at which one node can wirelessly communicate with another.

- Absorption: action of reducing the amplitude of a radio signal. Water is known to be radio-absorbant.

- Bit Error Rate (BER): number of erroneous bits/total number of transmitted bits

- Packet Error rate (PER) number of erroneous packets.total number of transmitted packets

6.3 Measurement

- Precision: degree of mutual agreement among a series of individual measurements.

$$p(\%) = (IC95\% / x)\ 100$$

IC = confidence interval 95 % (= t sn-1/√n)

- Accuracy: degree of conformity of a measured quantity to its actual (true) value.

$$e(\%) = (X - vref / vref)\ 100$$

X = average of value
v ref = reference value

- Quantification Limit: minimum value that can be measure with acceptable precision and accuracy

$$LQ = X_{n=8} + 10\ S_{n-1}$$

X = average of values for 0
Sn-1 = standard deviation

- Range: Interval of values where can be obtained the precision and accuracy defined.

- Productive Cycle: minimum interval of time between two consecutives maintenance operations, with autonomous working of system and compliment of range of measures.

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