UNDERWATER ENVIRONMENT MONITORING DEVICES INTEGRATION WITH VIRTUAL SCENARIOS IN REMOTELY OPERATED VEHICLES SIMULATOR

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This paper presents an approach to integrate underwater sensor networks and a proposed common framework model for multi-purpose devices to be deployed around offshore oil and gas drilling exploration areas, as well as on other types of concrete or steel structures available at sea. The study is focused on underwater sensor devices called "Safe-Nets" developed within the VMAX PerrySlingsby ROV Simulator environment. Furthermore, we are looking into environmental safety and applications in order to justify the costs of these underwater data collection modular devices and we address the deployment challenges using remote operated vehicles (ROV) in scenarios done on the ROV Simulator.

Keywords: Underwater Safe-Nets, Offshore Sensor Data Collection, ROV Simulation, Optimal Sensor Location, Object Modeling

1. Introduction

Both the vehicle technology and the sensor technology are mature enough nowadays to motivate the idea of underwater sensor networks. Although, there are no routinely operational underwater sensor networks, their development is imminent [1]. Recent advances in electrical engineering, telecommunications and computer science have converged into the field of wireless sensor networks [2], however, in order to turn this idea into reality, one must face the problem of costs of development and implementation.

We named our data collection sensor networks around offshore structures "Safe-Nets" trying to foresee the possible applications of these underwater sensor networks. If they were to be deployed around offshore exploration areas in the nearby future, these Safe-Nets could become the background infrastructure which could enable pollution monitoring, geological prospection and oceanographic data collection, even disaster prevention systems – including earthquakes and tsunami

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detection warning alarm in advance. Furthermore, these sensors could in fact improve offshore exploration control by replacing on-site instrumentation data systems used nowadays in the oil-industry system nearby well heads or in well control operations.

It is instructive to compare terrestrial sensor networks practices to current offshore approaches. While land networks have very cheap nodes enabling short-range communication, have dense deployments, at most a few hundred meters apart - by comparison, underwater wireless communication used typically today is very expensive ($10.000 per node or even more, considering the deployment costs), the network nodes are quite sparsely deployed (few nodes, placed kilometers apart) and are usually sending information directly to a base-station over long ranges [3]. We seek to overcome each of these design challenges, developing underwater sensor nodes that can be used for different practices, having the same framework and different module options ready to be installed. Having the link with offshore construction sites at hand could provide inexpensive sensors, densely deployed and communicating peer-to-peer, by underwater wire.

The scope of this research of the current developments in underwater sensor networks is to determine the most efficient way of deploying the safe-nets around offshore operations areas: oil and gas drilling and exploration facilities, including all types of platforms, jack-ups, jackets and spars, wind or wave energy producing turbines. All types of offshore concrete or steel constructions, fixed or tethered, could sustain different sensors and also provide the necessary electrical power requirements and moreover, satellite communication to the global Internet.

This paper is structured as follows: Chapter 2 describes the needs for a standard device due to the deployment challenges, highlighting the benefits of using a common modular framework in underwater environment monitoring tasks. Chapter 3 presents the remotely operated vehicle and ROV simulator with the hardware structure configuration considerations and details of the software used. Chapter 4 is dedicated to the development and implementation of the virtual scenarios along with the modeling challenges encountered. Chapter 5 ends the paper with study conclusions and future development work.

2. Common Modular Framework

There is a need for a common standard easy-to-use device framework for all multi-purpose underwater sensors and this framework should be modular in order to accommodate various sensors for future use. Marine operations and stranded locations make this modular approach best-suited for application development, providing the maintenance characteristics needed for prolonged use.

We considered the buoyancy capabilities and pressure dissipation characteristics needed for a stand-alone device launched at sea and we started with an almost spherical model with modular layers (Fig. 1). If tethering should be needed, a small O-ring cap on one of the sphere's poles can be mounted.

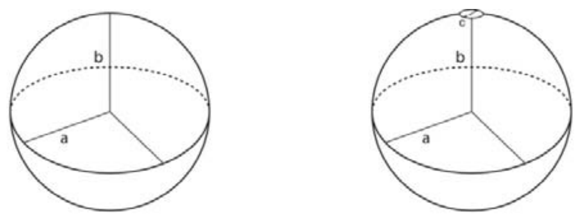

Fig. 1. Spherical-shaped model designed for common framework for devices; a >= b; c) is tether/cable entry point diameter

These safe-net nodes must possess self-configuration capabilities, meaning that they should be able to coordinate their data communication handshake protocols and operations by themselves. Some of the major design challenges involving the deployment of underwater multi-purpose sensors have been identified previously by [4], therefore in the following we will highlight our best-suited solutions to overcome each of the challenges of deploying sensor devices into the harsh environment of the sea:

2.1 Power supply

Usually batteries are the main power source in underwater nodes deployment and there are very many developments in the area of “sleep-awake” policies and communication protocols for underwater networks. Until now, there were several attempts to deploy underwater sensors that record data during their mission, but they were always recovered afterwards. This did not give the flexibility needed for real time monitoring situations. We are looking for prolonged use and for network devices using a framework that is maintenance-free, as much as possible. These embedded networked devices, which consist of processing units, various sensors and a power supply, usually in the form of batteries, can be deployed in an interest area around pre-existing offshore structures and relay important data back to a base station, where it could be stored, processed and analyzed. However, if they were to be tethered to the offshore structure and considering that most of the offshore structures nowadays have power facilities, some of them even from renewable energy systems, we could exclude the batteries and use the cables to supply the devices with the power they need (e.g.: autonomous buoys with solar panels which are currently undergoing researches [5], [6]). We are also analyzing in-depth the connectivity to renewable energy systems using wave energy: attenuators type - Pelamis Wave Converters [7]; symmetrical axial absorption points – WaveBob [8], AquaBuoy [9], Powerbuoy [10]; wave level oscillation converters – Oyster [11] and overtopping devices – WaveDragon [12]. A possible underwater network implementation is presented in Fig. 2, where different types of sensors have been deployed nearby pre-existing offshore resource harvesting and transport structures. Based on the different instrumentation systems needed, sensors types may have different coverage areas (e.g.: sensor 1 is equipped with a video sensor and this active underwater camera has only a vision cone; sensors 2 and 3 have partial or full sphere-shaped coverage, within meters around)

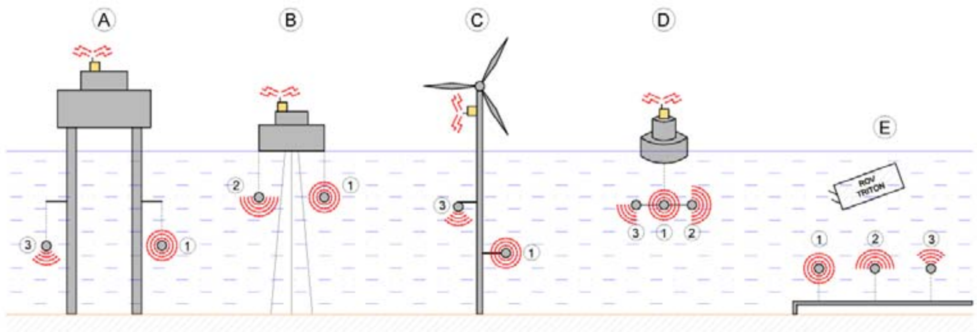

Fig. 2. Underwater Safe-Net possible implementation with ROV aid and different sensor types.: A) Jack-up Rig, B) Semi-submersible, C) Wind Farm, D) Autonomous Buoy, E) Cables/pipelines

2.2 Communications

Regarding underwater communications, usually the typical physical layer technology implies acoustic communications. Radio waves have long distance propagation issues through sea water and can only be done at extra low frequencies, below 300 Hz. This requires large antennae and high transmissions power, which we would prefer avoiding. Another approach for underwater communications is the optical possibility. The primary advantage of this type of data transmission is the higher theoretical rate of transmission, while the disadvantages are the range and the line-of-sight operation needed. We did not consider this as a feasible solution due to marine snow, non-uniform illumination issues and other possible interferences. The communication bandwidth can be provided in the same manner by satellite connections which are usually present on offshore facilities [13]. If linked to an autonomous buoy, the device provides GPS telemetry and has communication capabilities of its own, therefore once the information gets to the surface, radio communications are considered to be already provided as standard.

We do not intend to mix different communication protocols with different physical layers and will analyze the compatibility of each with existing underwater acoustic communications state-of-the-art protocols [14], [15] and routing algorithms [16], [17]. Our approach will be a hybrid system like the one in Fig. 3 that will incorporate both tethered sensors and wireless acoustic where absolutely no other solution can be implemented, e.g.: a group of bottom sea floor anchored sensor nodes are implemented nearby an oil pipe, interconnected to one or more underwater "sinks", which are in charge of relaying data from the ocean bottom network the a surface station [18].

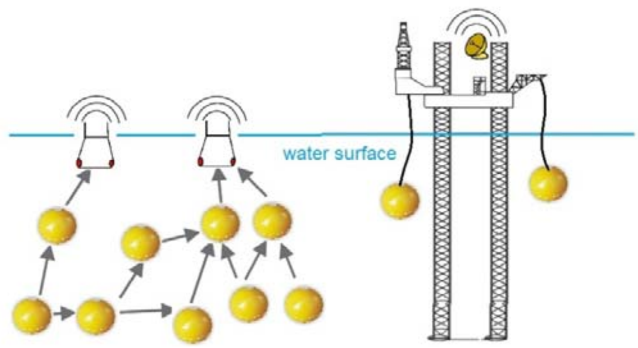

Fig. 3. Underwater device deployment in close proximity with autonomous and a jack-up rig

3. Underwater Deployment Equipment

A remotely operated vehicle (ROV) is a non-autonomous underwater robot. They are commonly used in deep-water industries such as offshore hydrocarbon extraction. ROVs are unoccupied, highly maneuverable and operated by a person aboard a vessel by means of commands sent through a tether (sometimes referred to as an umbilical cable), which is a group of cables that carry electrical power, video and data signals (Fig. 4).

We are using PerrySlingsby Triton XLS and XLR models for the remote operated vehicles (ROVs), which are available in the Black Sea area. Whilst having the desire for deploying such networks on a large scale, we can only think for a test bed and beforehand we are creating simulation scenarios on the VMAX ROV Simulator, as simulation helps preventing any damages to the ROV or subsea structures and prevents any real-life impossible design-situations to occur.

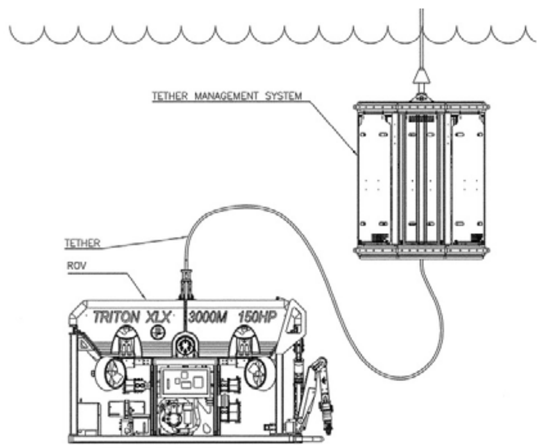

Fig. 4. ROV Triton XLX and Tether Management System (TMS)

The movement of the ROV's robotic arms, however good dexterity and degrees of freedom they may have, sometimes are physically limited in motion and capabilities. We address these situations and try to find best solutions for deploying and securing the devices by anchoring, tethering or fixing to their respective structures.

We have identified more than 4 working-class ROVs in the Black Sea area, operating in Romania's territorial sea coast line, out of which at least 2 are manufactured by PerrySlingsby U.K.: Triton XLX and XLR, , which led to our models used in simulation scenarios. The ability to have sensor nodes physically distributed near offshore oil-fields brings new opportunities to observe and monitor micro-habitats [19] or wide-area environmental systems [20]. The ROVs are used in offshore oilfield production sites, underwater pipelines inspection, welding operations, subsea BOP (Blow-Out Preventer) manipulation as well as other tasks: seabed mining, aggregates industry – used to monitor the action and effectiveness of suction pipes during extraction; preparation and arrival of a Jack-up or Semi-Submersible drilling rig, geotechnical investigations, submarine cables surveys, nuclear industry – intervention or inspections; investigations, monitoring of ports or homeland security.

Mounted on our XLS ROV we have a Schilling Robotics' TITAN 4 manipulator (Fig. 6), which offers the optimum combination of dexterity and strength. The exact movements of the joints of the 7-function joystick console (Fig. 5) above the sea level represent the movement of the Titan-4 underwater. Constructed from titanium, the TITAN 4 is uniquely capable of withstanding the offshore harsh environment and repetitive needs, as well as providing the dexterity for the job. We also have a Schilling's RigMaster five-function (Fig. 7), rate-controlled, heavy-lift grabber arm that can be mounted on the other side of the ROV.

Fig. 5.Master Arm 7-F Console

Fig. 6. Titan 4 Master Arm 7-F

Fig. 7. Rig Master 5-F

With these two manipulator systems, with small adjustments and auxiliary tools any type of sensors can be deployed or fixed on the ocean bottom or to any offshore structure. In order to safely deploy our safe-nets' sensors into the water and fix them to jack-up rigs metallic structures or to any other offshore constructions we first try to develop models of those structures and include them into a standard fly-alone ROV simulation scenario.

4. ROV Simulator Scenarios and Modeling Issues

The VMAX Simulator is software and hardware package intended to be used by engineers to help in the design process of procedures, equipment and methodologies, having a “physics based simulation” for the offshore environment. This is a two-steps process as any object's model has to be created in 3D Studio Max software and afterwards it can be programmatically be inserted into the simulation scenario. The simulation scenarios are initialized by a series of .Lua scripts, which is very similar to C++ programming language and The VMAX Scenario Creation is *open source*. The file names end with .lua extension and are recommended to be opened with jEdit editor. This is also an open-source editor which requires the installation of Java Runtime Environment (JRE).

The VMAX-PerrySlingsby ROV simulator was the starting base for a scenario where we translated the needs of the ROV in terms of sensor handling, tether positioning and pilot techniques combined with the specifications of the sea-floor where the safe-nets will be deployed [21]. We have altered the simulation scenarios in Fig. 8 in order to obtain a better model of the Black Sea floor through-out Romania’s coast line, which usually contains more sand because of the Danube sediments coming from The Danube Delta. Geologists working onboard the Romanian jack-ups considered the sea-floor in the VMAX ROV Simulator very much alike with the one in the geological and oil-petroleum interest zones up to 150-160 miles out in the sea. Throughout these zones the water depth doesn't exceed 80-90m, which is the limit at which drilling jack-up rigs can operate (legs have 118m in length).

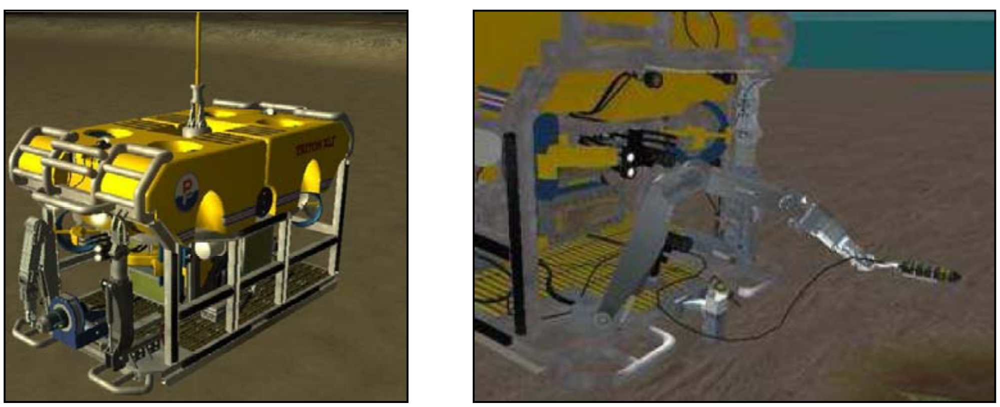

Fig. 8. ROV Triton XLX in simulation scenario and extending Master Arm 7F Titan4 Manipulator

The scenarios are initialized by a series of .Lua scripts and the typical hierarchical file layout for a scenario includes: Resources, Assets with Bathymetry, Lua, Manipulators, Tooling, TMS (Tether Management System), Vehicles, Components and IP (Internet Protocol communications between assets) as major components. Bathymetry directory contains terrain information about a specific location, where we could alter the sand properties on the sea floor. The terrain stored here may be used across several scenarios.

We can add a graphic asset by using the template for the bathymetry part. The collision geometry can be later generated based on the modeled geometry. We remind that the simulator software is open-source [22] and we present in the following lines some of the parts of the basic scenario provided with the full-up simulator which we modified with comments in order to accommodate our specific needs:

```
graphicAsset {
assetID = "bathymetry",
castShadow = true, -- can be false for very flat terrain
-- Our terrain model = "assets/Bathymetry/TER_500m_v2.0/TERBLKSEA_500m_v1.0.ive",
receiveShadow = true,
scale = { 2, 2, 2 } -- specific to this particular model}
-- We changed the environment table to look like this:
environment = {
assembly = {
-- Various items in the environment starting with bathymetry.
parts = {
-- add the bathymetry based on a template
createFromTemplate(templates.bathymetry, {
collisions = {
-- The first item in the array is for the collision
-- geometry automatically created from the model. {
-- set the area over which the bathymetry spans
size = { 100, 100, 1 }, -- must be specified}
-- collision primitives may be appended to this array},
-- set the depth of the bathymetry
position = { 0, 0, REFERENCE_DEPTH - 20 }}),}
constraints = { },
selfCollide = true,},
bathymetryPartName = "bathymetry",
pickFilter = { "bathymetry" },
currentDirectionTable = { 0 },
currentSpeedTable = { 1 },
depthTable = { 0 }}
```

The spherical model framework of the sensor, the basic node of the safe-net, will prove to be very difficult to handle using the manipulator, as it tends to slip and the objective is to carry it without dropping. Therefore we have designed a "cup-holder" shape for grabbing more easily the sphere. If the sensor contains also a cable connection, the cable will not be tampered by the grabber, as it can be seen in Fig. 9:

Fig. 9. Basic sensor device holder auxiliary tool designed for simulation

We have also modeled different types of modular sensors based on the common framework model presented in Chapter 2. As a result we have stumbled upon other issues that may interfere in the real actual process of implementation of our Safe-Nets, therefore we tried to foresee problems that may arise.

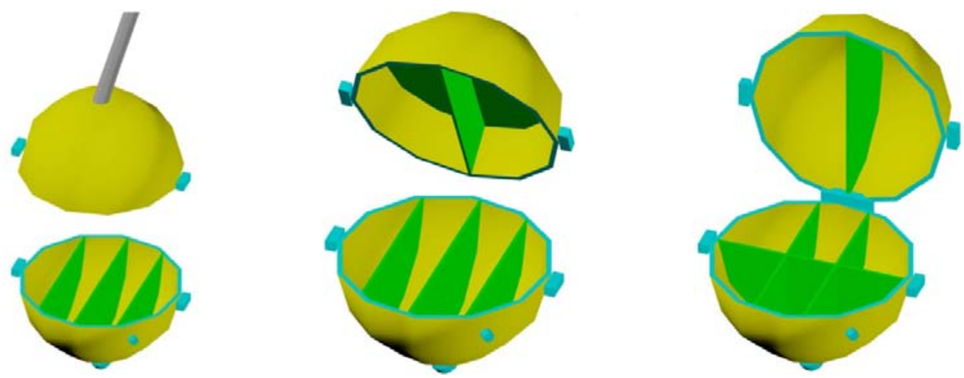

Fig. 10. Sensor devices modeled in 3D based upon common modular framework

The sensor devices modeled in 3D have drawers that allow different electronic components modules to be fitted inside, as well as some are also taking into consideration the cable management issues (Fig. 11). We have chosen a simple sealing mechanism for the devices with clamps that allow sealing the top and bottom sides through a rubber O-ring and moreover we have fitted them with a sealing valve for vacuum possibilities. If the sensor is not going to be tethered, then the upper hemisphere leaves room for a power supply unit or transformer, if this is necessary. On the same modular approach we designed a pollution detection sensor fitted with an aperture membrane, as it can be seen in Fig. 11. Within our endeavors in the VMAX PerrySlingsby ROV Simulator we had real problems caused not only by devices shape and physics interactions with the two manipulator systems, but also because of the marine currents and wave lengths and heights which can be also set as separate variables. This issued the idea of deploying several sensors at once, for example when connected to an autonomous buoy or spar which is highly dependent to water movement and therefore more difficult to approach. The modular common framework is also design to fit multiple sensors in a line (Fig. 12).

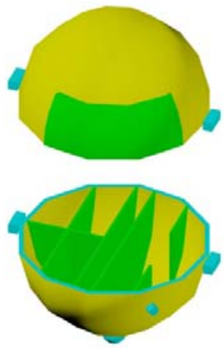

Fig. 11. Pollution detection sensor w/ membrane; Fig. 12. Multiple sensor deployment method

6. Conclusions and future development

This paper is following the development of the PhD research of Optimizing Real-Time Applications for Marine Operations Using Modern Modeling and Simulation Methods and presents the major challenges in designing the devices common framework and the simulation scenarios for sensor deployment methods using a ROV, being the first step for our Safe-Net sensors to be implemented into monitoring applications for offshore industries.

The simulation allows the pilot to prevent any situation where deploying underwater sensors safe-net in offshore drilling operations surrounding areas could endanger the remote operated vehicle itself or the underwater structures. We have created a simple scenario in which we use a PerrySlingsby Triton XLX ROV connected to a TMS (Tether Management System) and where we can use the physics of the robotic arms in order to understand which movements are going to be needed in order to implant sensors of different sizes into the ocean floor, submarine cables, as well as nearby other types of subsea structures. Moreover, we are currently looking into mathematical proven models [23] in order for completing a small grid around a particular structure, with best-positioned sensor nodes [24] to cover as much sea territory as possible. We analyzed thoroughly these onshore models which can be used by analogy to marine environment, but further studies must take into account environment constants in order to better suit the physical and chemical properties of sea water.

We have emphasized the benefits of deploying such safe-nets and we address state-of-the-art ideas and possible collateral implementations of different other applications like coastal areas military surveillance or disaster prevention systems (earthquake, tsunami detection, so on and so forth) all in order to overcome the biggest challenge of all: price of implementation.

The main contribution of the thesis is brought by the development of a common modular framework for all underwater sensors deployable by ROV means and the development of the programming algorithms inside VMAX PerrySlingsby ROV Simulator in order to accommodate the simulation for these various purpose devices. Using the same network node for more than one application can be essential for cost-wise analysis and moreover, this modular compatibility can improve the financial desirability of any future projects.

Experimental results implied a best location deployment analysis around a jack-up rig and simulation scenarios were adapted in order to better understand the needs of rig's routine works compliance with the sensors position.

We haven't obtained yet a model for all types of underwater structures yet, but we also want to address concrete structures and cylindrical or truncated cone shaped structures of the offshore wind turbines. Furthermore, we try to suggest applications and extension possibilities of this approach and more algorithms should be tested before actually launching sensors into the water and furthermore, extra tools should be developed and their electrical or hydraulic link to the ROV itself should be investigated, also on the simulator side.

We are looking forward to patent the physical devices as a result of our research in order to be the first viable option on the market when the legal coerciveness or financial needs will imply the development of underwater sensor networks surrounding offshore oil and gas or production sites.

In short, this article has analyzed the necessity of considering the physical fundamentals of an underwater network development surrounding offshore structures.

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