From High Technology to Solutions: The Experience of iXSea

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1 Introduction

In any business school in the world, you will learn that there are just two ways to develop and lead a company: a manager must choose between being "techno-driven" or "market-driven". However, all previous success stories demonstrate that the reality is far removed from this highly theoretical vision: in most cases, successful development results from an overlap between an idea and a need. This means that in practice the main issue for a manager is to invent new concepts while getting a feel for market orientation and trying to reach the best decision as to 'when and how' the company can bridge the two.

In 2000, IXSea focused on a single goal: ensuring that it was capable of providing the right technical solutions ocean exploration would be looking for throughout the coming century.

Why this choice?

There can be no doubt that one of the challenges of the 21st century will be to become the masters of the largest part of our planet – its oceans – and it is also obvious that at present we have no idea of the means we will employ to accomplish that. However, what is absolutely certain is that all those involved in this challenge, scientists, oil and gas industries, naval forces, etc… have their eyes on the same goals: deeper, faster and easier!

For example, in just five years iXSea brought fiber optic gyro technology to unmanned underwater vehicles, designed USBL plug-and-play systems, democratized Synthetic Aperture Sonar and invented real-time magnetic imaging. We saw here a need for interdependence between wide-ranging R&D in optoelectronics, acoustics, signal processing and NMR, of which we had complete mastery in our research labs, and easy-to-use solutions for the most demanding applications.

The main purpose of the present paper is to look again at some of our technologies, and see how they could solve some of the most challenging underwater problems of the early 2000s, and also to describe the solutions on which iXSea is working in order to meet the latest challenges in positioning and imagery.

2 The technology upstream

We see ourselves as an enterprise made up of scientists and engineers. At every level in our managerial structure, iXSea breathes the same air of high technology and determination to push back further and further the known technical frontiers, the starting point being our human resources: the educational background of three-quarters of our workforce is of high technical level.

It is with this pool of men and women passionately committed to science and engineering that iXSea is inventing the technologies and concepts the sea will require tomorrow.

To illustrate the above, I propose to describe in detail one technology invented in our laboratories which have each yielded products that have made possible the emergence of systems and tools used today by oceanographers and surveyors the world over: the FOG, or Fiber Optic Gyroscope.

Our history in the field of FOG technology [1] goes back nearly 20 years, and we have provided key components that have enabled this technology to emerge at industrial level for the most stringent applications in terms of performance and reliability [2].

A FOG is a gyrometer, that is to say it is a sensor that can measure instantaneously the rotational speed of a mobile platform.

The FOG is based around the Sagnac Effect discovered in 1917 by a physicist called Georges Sagnac [3]. This is a relativistic phenomenon not dissimilar to the familiar Doppler effect.

To understand it properly, we need to look at the diagram illustrating the basic principle: a 'ring' interferometer, that is to say an interferometer composed of a coil of optical fiber which loops back on itself (cf. figure 1).

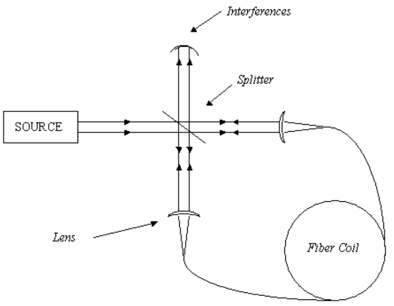

Figure 1: The basic principle underlying the FOG

The light from a single optical source is divided into two parts by a beam splitter, and the two light waves thus generated travel around the optical fiber coil in opposite directions. When they emerge from the coil, they have on the face of it traveled over the same optical path and they should therefore be in phase.

What the Sagnac Effect in fact says is that when the coil is made to rotate the two waves, when they emerge, will be out of phase (delayed) to a degree proportional to the velocity of the rotation.

$$\boxed{\Delta\phi = \frac{2\pi\,\mathbf{L}\,\mathbf{D}}{\lambda\,\mathbf{c}}\;\Omega}$$

The coefficient of this proportionality will depend on the geometric sizing of the coil (length L and diameter D), and especially its apparent surface area: the phase shift caused by the Sagnac Effect is in fact a measure of the flux of the rotational vector through the optical fiber coil, a little like magnetism or the familiar phenomenon of induction which describes how a current can be created by the flux of a magnetic field through an electrically conductive coil.

It is easy to understand why FOG technology enables currently unequalled levels of performance to be achieved: by increasing the apparent surface area of the coil, that is to say its diameter and its length, it is possible to increase the proportionality coefficient and therefore the detection sensitivity.

The diagram provided above simply illustrates the underlying principle and no FOG could actually operate in this way for a number of reasons, and in particular the dimensional stability of the optical alignments at the interfaces, and the fact that the sensor has zero sensitivity at low rotational speeds, since the intensity of the interference varies with the cosine of the phase shift. The optimum configuration for a FOG offering best performance is shown in figure 2.

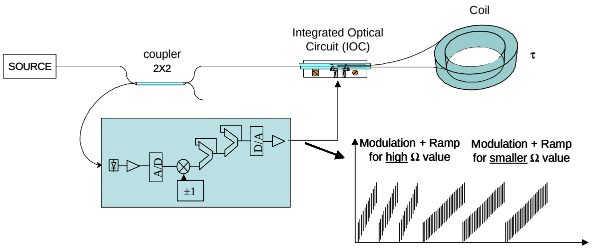

Figure 2: Optimum FOG configuration

By using this type of configuration, known as an ‘all-digital closed-loop hybrid’, the performance obtained makes it possible to attain the Holy Grail of rotation detection: stability better than 0.01 degree per hour, which in turn enables what is called inertial navigation, that is to say its use as a ‘black box’ without a GPS. In actual fact, the FOGs produced by iXSea perform even better than this and continue to improve as time goes by: for example, we manufacture the gyrometers for European Earth Observation satellites [4] and autonomous navigation units for nuclear attack submarines, and such gyrometers are in the 0.001 deg/h class, or 10^{-4} of the earth’s rotation [5].

3 From Technology to Equipment

Our mastery of the technology required upstream gives us independence and the capacity to adapt to potential market requirements.

Continuing our demonstration in relation to the FOG, our capability for high performance made it possible for us to propose innovative solutions to our customers very early on.

Like all gyrometers, FOGs are essentially the main components of Inertial Navigation Systems (INS), units which contain a minimum of three gyrometers and three accelerometers.

At every moment an INS can measure the position and attitude of a moving solid platform, which is generally a vehicle of some kind, for which we want to determine in real time six navigation parameters: latitude, longitude, altitude, heading, roll and pitch.

The accuracy of an INS in fact derives from the accuracy of its gyrometers, and this will drift with the passage of time. This might on the face of it seem paradoxical, since intuitively you could consider that if the position is defined by the double integration of the accelerometers, the position would drift according to the square of time and the stability of the accelerometers. But this is not the case!

What is often forgotten is that navigating along a straight line on the surface of the Earth, assumed to be roughly spherical, actually amounts to traveling on a great circle, and therefore rotating. This means in fact that the stability of a gyrometer will determine, taking the Earth’s radius into account, the drift in the position given by the navigation unit [6].

INS Drift in Nm/h = 60 x Gyro Bias in deg/h

Class 0.01 deg/h gyrometers therefore give us INS units whose stability in ‘pure inertial’ mode will be 0.6 Nm/h, which is quite sufficient for aircraft navigation, but far from good enough for an AUV!

To arrive at satisfactory performance it is necessary to help the INS out using other types of sensor made statistically independent of the navigation unit by optimized real-time filtering of Kalman type. Where AUVs are concerned, we can use auxiliary acoustic systems, usually Doppler logs (DVLs), or in some cases acoustic positioning systems (USBL) [7].

Given the high accuracy of a DVL’s stable measurement of the speed of travel over the sea bottom, of the order of millimeters per second, the speed drift of the navigation unit can be corrected using this information, which will improve, thanks to the Kalman filter, the information on gyrometer and accelerometer bias, which will also by the same token enhance the accuracy of the determination of position and attitude. This means that the Kalman filter method for correcting the navigation unit is infinitely more effective than simple dead reckoning. In the last analysis, the accuracy of the positioning will be limited only by the DVL’s own drift, which is around 3 m/h.

After having placed on the market the first optical fiber gyrocompass in 1997 – the Octans™ – iXSea successfully introduced the first optical fiber INS in 2001 – the Phins™ – which is also the only INS specifically developed for use in AUV navigation.

Its dual characteristics led to its adoption by most builders of AUVs. First and foremost, it is a specific feature of FOG technology that compared with the older gyrolaser technology (RLG) it consumes much less power and offers significantly greater reliability and longevity, qualities the space industry found attractive. Secondly, the Kalman filter in the Phins was developed on the basis of the specific characteristics of the marine environment and of acoustic sensors, which is not the case for more conventional INS units developed for civil or military avionics use.

The inertial navigation units made by iXSea are not used only for autonomous vehicle navigation, but also for stabilizing platforms and compensating for swell-induced movement in supporting structures.

On the basis of IXSea's many years of experience in acoustic positioning, and particularly its development and manufacture of the world's longest-range USBL, the Posidonia™, we came up in 2003 with the idea of merging USBL and INS to create a new type of totally portable USBL that can be easily deployed on any type of ship without prior calibration. This product was the GAPS™ [8].

Figure 3: OCTANS, PHINS and GAPS

Specifically, the fact that the GAPS includes an attitude detection unit accurate to 0.01 deg which requires no corrections for attitude offset, in addition to its use of the most modern chirped acoustic technology, enables the position of objects to be determined up to distances of 4,000 meters with a CEP (Central Equal Probability) accuracy of 0.2% slant range.

The 3-dimensional design of the acoustic antenna has been specially engineered to make it possible to position objects within a 200-degree cone, enabling ROVs to be tracked vertically at great depths at the same time as towed fish behind the ship traveling horizontally and just at the surface.

But one of the main advantages of the GAPS is its proprietary algorithm developed by iXSea's ablest mathematicians. The Kalman filter optimizes the merging of data from the inertial navigation unit and the acoustic antenna and calculates in real time the best estimate of the trajectory of the submarine vehicle. Among other things, this makes it possible to calculate the position of an object at all times, without delay and at an arbitrarily chosen frequency, making the monitoring of a remotely operated object such as a ROV more straightforward and intuitive.

4 From the Equipment to the Solution

Inertial, acoustic and hybrid products for navigation and positioning can also be mutually interfaced and supplement each other to provide a solution that will match the needs specific to a given application.

For example, it is standard practice today to correct an AUV's INS using data from a USBL which is itself corrected by a GPS. We have also carried out development in the reverse direction: when the USBL loses the GPS data, it is the inertial unit that corrects the USBL at the surface, thereby enabling the surface platform to retain its navigation capability.

In other respects, the merging of acoustic and inertial technologies commenced by iXSea just a few years ago has not focused solely on positioning issues.

Indeed, we decided two years ago to develop a Synthetic Aperture Sonar (SAS), capitalizing on our mastery of inertial technologies, acoustic transducers and real-time algorithms. We placed our own SAS on the market recently, in March 2006: this is the Shadows™.

Figure 4: Shadows

The basic principle underlying the SAS is to use the speed of the structure on which it is installed to create synthetically a virtual antenna larger than the physical antenna, thereby enhancing the resolution that would otherwise be obtained conventionally with a standard antenna of the same length as the physical antenna.

The idea is to reconstitute along the path of the antenna its displacement during the system's coherence time.

It is of course possible to use the redundancy of the sonar image to reconstitute the antenna's curved trajectory, but although the algorithm is effective on paper, in actual practice if the design of the SAS is based on correction of the trajectory by the image it will be fairly unstable and sensitive to outside disturbance.

The idea here is to use an INS for accurate measurement of the antenna's micro-displacements to reconstitute the curved trajectory of the physical antenna in order to synthesize the virtual antenna.

In practice, it is our detailed knowledge of the behavior of our INS and the very high quality of our FOGs that made it possible to rise to this challenge. Once again, in the last analysis what is important is to get the technology right …

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