KETmaritime Case Study 5 – MEMS (Micro Electromechanical Systems) Marine Applications

A pioneering scientific centre in northern Portugal has led a major two-year project studying advanced manufacturing technologies with the potential to revolutionise the Atlantic maritime sector. The International Iberian Nanotechnology Laboratory (INL) located in Braga is the lead partner in the €1million 'KETmaritime' project backed by the European Regional Development Fund. Project coordinator Ana Vila said the INL is now releasing details of a fifth case study focusing on 'Micro Electro-Mechanical' Marine Applications. She said the pan-European project identifies how advances in this field are driving developments across marine navigation systems and autonomous exploration vehicles, as well as structural health and ocean weather monitoring systems and biological and marine pollutant studies.

Key findings from the KETmaritime project are now being revealed following two years of intensive international work involving a world-class consortium of partners across Spain, Portugal, France, Ireland and the UK. Its mission is focused on identifying KET (Key Enabling Technologies) to meet the future needs and demands of the Atlantic maritime industry.

Project partners include French multidisciplinary research laboratory CIMAP (CEA group), Portuguese maritime economy association Fórum Oceano and Spanish technology centre IDONIAL. Ireland's national centre for marine and renewable energy MaREI, UK marine cluster organisation Marine South East and Spanish non-profit research association AIMEN.

A total of five detailed case studies have been produced under the €1million initiative funded by the Interreg Atlantic Area Program, via the European Regional Development Fund. Topics include 'Advanced Manufacturing Shipbuilding Applications', 'Nanotechnology Marine Applications', 'Marine Industrial Biotechnology', 'Photonic Marine Applications' and 'MEMS (Micro Electromechanical Systems) Marine Applications'.

IDONIAL – Research, development and innovation addressing new industry challenges

The fifth case study led by IDONIAL in collaboration with Marine South East focuses on the use of Micro Electromechanical Systems (MEMS) for a variety of marine applications (access http://ketmaritime.eu/media/ to view the full report). The International Iberian Nanotechnology Laboratory (INL) also provided key input into the report.

Spanish tech centre IDONIAL was set up in 2019 resulting from a merger between the ITMA and PRODINTEC centres with 40 years of collective experience. The centres opted to join efforts to deliver R&D&I addressing new challenges across industry. IDONIAL provides tailor-made solutions related to the development of materials, advanced manufacturing and the digital industry through technological development and innovation. Its team includes more than 160 professionals, delivering more than 120 R&D&I projects each year.

'Moore's Law' – the unstoppable march of microelectronic technology

The now famous 'Moore's Law' is a computing term which originated around 1970, stating that processor speeds, or overall processing power for computers will double every two years. Electronic technology has evolved rapidly ever since. In the last 50 years, silicon-based electronic technology has moved from housing a transistor in one hundredth of a millimetre, to requiring only 7 nanometers by the end of 2018 - a reduction factor greater than 1400 times.

The speed and impact of this impressive advance has been felt across society. Notable results include calculators, portable electronic devices, personal microcomputers, mobile telephony, embeddable electronics, flexible electronics, optoelectronics and electromechanics. These advances have driven by demand for reduced-scale electronic design and manufacturing. They have been further aided by the evolution of electronic architecture based on silicon. This development is not only based on a progressive miniaturization (and the exponential increase of calculation power), but alternative models and architectures of computation. The continued exploration of alternative concepts transcending the performance limits of silicon is also driving innovation.

All factors have exponentially increased the processing power of chips, reduced electrical consumption and in general given rise to a whole generation of applications and devices. Traditional 'microelectronics' which has now evolved into 'nanoelectronics' is recognized as a 'Key Enabling Technology' by the European Commission and will continue to play a major role driving advances and innovation across many industries in years to come.

'Silicon Technology' - electronic evolution in the last 50 years

Many electronic developments over the last 50 years are based on what is often called 'silicon technology'. To understand why silicon has been the basis of this evolution, it is necessary to explain a series of basic concepts.

Current electronic technology is based on the use of semiconductors. While it would be logical to assume any metal would be a good candidate for the manufacture of electronic devices, its condition as pure conductor means that the electric current cannot be modulated. Semiconductors are elements of the periodic table known as 'metalloids' or 'semimetals', because they have properties halfway between metals and non-metals. Thus, elements such as silicon, gallium or gallium arsenide are some of the best-known semiconductors. However, there are also organic semiconductors.

An additional peculiarity of semiconductors is that their behaviour can be modified in a relatively simple way through a process of 'doping'. By adding impurities, it modifies their electrical behaviour altering the number of free electrons and 'free holes' for these electrons movement. Silicon has emerged as a fundamental semiconductor for several reasons. It is abundant on Earth, being the most common element in the Earth's crust, and therefore cheap. It also has great resistance to high temperature. The development of semiconductors and design and manufacture of the vast majority of electronic architectures used in the last half century, are based on silicon technology.

Gyroscopes and Accelerometers

The production of progressively smaller scale electronic systems has influenced a reduction in scale of associated mechanical systems. Two specific cases used in everyday life in great volume across the globe include gyroscopes and accelerometers. Both inventions are implemented in almost all current mobile phones through MEMS components, detecting changes in position and orientation of the device, as well as gestures. In practice these are useful for movement control systems and navigation applications. This technology is mass produced and integrated into a huge variety of products.

A gyroscope is composed of a symmetrical body with rotation capacity, which rotates continuously around an axis of symmetry. When it is subjected to a force that tends to change the orientation of this axis, it is capable of retaining its orientations, since it is the symmetrical body's own rotation that generates forces capable of opposing external forces, nullifying the external action. An accelerometer, meanwhile, consists of two facing metal plates, one fixed and the other mobile, working as a condenser which capacity can vary, depending on the distance between said plates, and this distance depending of an external acceleration.

'Lab on a chip'- Micro Electro-Mechanical Systems (MEMS) in maritime applications

The possibility of manufacturing mechanical elements at micrometric scales has opened the doors to the development of multiple devices with different sensory capabilities. In general, we can differentiate at least six types of sensors:

Firstly, 'mechanical sensors' are capable of measuring pressures, deformations, strain loads, torque and position. Secondly, 'optical sensors' detect light emissions at the wavelengths while 'temperature sensors' are capable of measuring temperature and variations in it. Fourthly, 'acoustic sensors' perceive and measure sounds and vibrations while 'chemical sensors' are capable of measuring PH, detecting contaminants or certain substances and elements. Finally, 'biological sensors' detect microorganisms or pathogens.

Micro Electro-Mechanical Systems (MEMS) also serve as the technological basis for the 'lab on a chip' concept, used to designate devices/platforms with sensory capacity, capable of providing specific and relevant information from the environment, in an agile, simple and affordable way. It is possible to identify a series of general applications of MEMS in the marine and maritime fields:

Within navigation, the development of MEMS sensors is key not only for the implementation of location and positioning technologies, but also for the development of complete mobile platforms (potentially autonomous) for the collection and distribution of data at open water environments. In addition, weather monitoring and forecasting, traditional navigation and fisheries activities, as well as partially unassisted activities (associated renewable energy or aquaculture fields) require complete sets of sensors capable of monitoring environmental variables. This helps produce short- and medium-term weather prediction systems driving productivity.

MEMS are further used for monitoring water properties and composition. This is highly valuable for maximizing aquaculture activity, identifying potential pathogenic agents and unwanted variations of acidity, etc. MEMS technology can also be used to monitor marine structures. Any activity carried out continuously in marine environments is inherently subject to external aggressions, capable of deteriorating all structures in the absence of adequate controls and maintenance. MEMS sensors are now capable of measuring variations of the stresses and strains which structures are subjected to, essential to informing maintaining plans and preventing accidents.

Within marine biology and chemistry studies, sensor technology for the detection of analytes is also being developed at microelectromechanical levels. In combination with microfluidics, it is feasible to develop devices of very small size, with the capacity to act as real laboratories/labs on a chip. The field of marine exploration also benefits from MEMS technology. This wide-ranging discipline involves marine bed surveys, the early detection of earthquakes in the sea as well as marine deposits. The implementation of MEMS technology in autonomous or semi-autonomous operations can further aid underwater prospecting and the discovery underwater resources.

Navigation Systems

Inertial navigation systems (Inertial Measurement Unit IMU) are capable of establishing the position of an object without external references, in a similar way to GPS technology. These systems use a combination of sensors, mainly accelerometers and gyroscopes, with a computing system to obtain the position and speed of an object. In this way, these systems are able to detect displacements in geographical position, inclination and rolling, changes in the direction and speed, as well as orientation, without interference which GPS can be subjected to. In the maritime field, this is especially useful for devices that require continuous and precise positioning, for example autonomous navigation systems which are expected to rise in use exponentially in the coming years.

These systems have already been developed at the MEMS scale, with chips available on the marketplace combining accelerometers, gyroscopes and motion processing units in very small packages. An example is the INVESENSE MPU6050 device. This class of component is frequently used for planning and development of IMUs across different marine applications.

The MPU6050 for example has been used for a series of developments and investigations in the recent past including the implementation of 'digital IMUs' to increase the accuracy of hydrographic surveys, IMUs for vessel and offshore piping surveys, ship vibration monitoring systems using wireless sensor networks and the development of self-rescue systems for autonomous underwater vehicles using micro-inertial sensing modules. It has also been used within mobile augmented reality systems for marine navigation, self-balance systems for naval operation vehicles, structural health monitoring of offshore assets using wireless sensor networking and load monitoring of wind turbine blades.

Major benefits including accessibility and low cost make MEMS highly suitable for marine applications that demand precise control of the positioning, location, and other variables associated with movement.

Autonomous exploration and exploitation of marine resources

The marine environment is fast becoming a major source of activity beyond traditional industries of fishing and oil and gas. Fast emerging sectors include marine renewable energy, deep-sea mining, offshore aquaculture and algae farming. The future development of these applications is largely based on two factors.

Firstly, obtaining information to minimise the cost of operation. Due to its very nature, all the activities carried out in the marine environment incur significant operating costs, either linked to preparatory activities for the exploitation of resources (eg; mapping and survey of sea beds in order to characterize marine resources, mapping of tides and waves for the production of energy, wind maps), or the exploitation itself (adjustments and maintenance based on the monitoring of environmental variables, in the search for the parameters of operation that maximize production).

Secondly, autonomy of operations. Much of the productive activities in seas and oceans take place at great distances from the coasts where intervention, direct monitoring and maintenance imply significant operating costs. In this sense, a large part of the profitability of these operations depends on the ability to develop autonomous technology, capable of being monitored and operated remotely, across complex networks driving operational efficiency at all times.

MEMS is therefore critical for the future development of many marine activities with the capacity to incorporate sensors capturing relevant information to monitor and adapt activities at sea, including temperature, pressure, winds, currents, position, waves etc. Due to constant advances in manufacturing systems involving MEMS, costs are being reduced with increasing integration in specific embedded electronic systems, including navigation, detection, monitoring systems.

MEMS play a fundamental role in the development of control systems for offshore applications, which together with wireless communication capabilities allow the configuration of systems with autonomous control and remote-control capabilities. They are also easily integrated into global networks through which deep optimizations can be performed. In turn, MEMS provide the basis for the development of navigation and autonomous vehicles, which are becoming increasingly compact and capable of obtaining information at sea.

Monitoring and prediction of weather

The practice of weather monitoring and prediction at sea is of unquestionable value for offshore marine activities. Weather is a constant variable and can affect the safety of maritime operations, low-altitude aerial navigation and even performance. For example, maintenance operations of offshore wind structures is more efficient when carried out in periods of weak winds.

One of the clearest examples illustrating the impact of sensors in the most cutting-edge applications within the marine environment is the implementation of MEMS sensors in buoys. NexSens has developed a platform on a buoy in which diverse sensors can be installed, such as the hardware SVS-603 from Seaviewsystems. This small electronic board houses inertial sensors for the monitoring of the heading, wave height, wave period and wave direction. Systems of this kind can be of great importance for developing applications in the field of marine renewable energies, where the characterization of tides and waves is of vital importance.

These systems are also capable of operating in combination with other buoys and with centralized information management systems, forming networks for obtaining complete information from the environment. Projects including LifeDEmowave are developing these kind of applications, focused on the design and prototyping of complex networks for the management of environmental information.

Structural Health Monitoring

Considerable investments are required to erect structures at sea. These structures naturally incur significant monitoring and maintenance costs, in order to ensure maximum durability and operational performance. This raises the sizeable challenge of efficient structural health monitoring. Nowadays this practice implements sensor networks capable of collecting and processing data in unified systems which allows monitoring complete sets of assets during their lifecycle. This involves sensors capable of measuring variables such as inclination, displacement, scour, the appearance of fractures, noise, vibration and leaks. The development of microelectronics has allowed as in other fields for the improvement, simplification and reduction of cost while boosting operational capabilities. The total integration of the sensorization technologies with wireless communication has also dramatically reduced drain on time, helping further optimize monitoring and maintenance tasks.

Due to the wide variety of sensors capable of capturing information for the monitoring of structural health, the case of extensiometric micro-gauges is suitable to illustrate the potential of MEMS applications. An extensiometric gauge is a deformation sensor, consisting of an electrical circuit that varies its resistance as a function of the forces to which the gauge is subjected. It does this in such a way in which it is possible to establish correlations and use them to evaluate the effort suffered from a structure.

In this sense, the use of MEMS technology allows the development of strain gauges not only of smaller size, but also with considerably more complex structures. This gives the MEMS strain gauges greater sensitivity and resolution, as well as greater resistance to impacts, thanks to its smaller size. There are many other examples of MEMS based inertial sensors being used for the monitoring of offshore structures, including wind turbine blades, with commercial sensors capable of carrying out vibration analysis.

Biologic and Marine Pollutants Studies

MEMS sensors also play a highly relevant role in the monitoring of biological and chemical agents. Several applications benefit from a detection capacity of different microorganisms and pathogens, including viruses and infections, acidity of waters, chemicals harmful to life, corrosion and biofouling control etc. In this area, most MEMS advances in recent years are related to the development of systems resulting from the fusion between electronics and microfluidics.

Microfluidics is the practice of designing and developing systems and capacities to process minute amounts of fluid, through the fabrication of structures equipped with microchannels. In these conditions, the behaviour of the fluids is different when compared to larger volumes, which translates into important differences in factors such as surface tension, speed and flow distribution. In these conditions and with such small channels, the processes that allow the detection of substances takes place very quickly and in a very localized way, making it possible for these devices to perform functions similar to traditional laboratory equipment. Therefore, the combination of microfluidics and microelectronics gives rise to the "lab on a chip" concept.

In general, devices of this type derive from previous developments on a macroscopic scale, in which the functionality has already been correctly validated and put to the test, and whose miniaturization offers a large number of advantages, such as a lower consumption of chemical reagents, high resolution and sensitivity, short product synthesis times, greater control over chemical reactions through more efficient control of concentrations, etc.

A number of remarkable experiences have been recorded across the ‘lab on a chip’ field of study for different applications within the marine field. Examples include the ‘Sea on a Chip Project’. This project led to the development of a detection platform, consisting of a network of chips equipped with sensors, located on the perimeter of a fish farm. This network of sensors is located on small buoys, with each chip (about 10 cm in total size) containing its own energy source, along with the chemical reagents necessary for analysis and the electronic components to receive and transmit data. Each chip is equipped with biosensors for the analysis of seven compounds from natural toxins to emerging contaminants, such as polybrominated compounds or antibiotics.

Furthermore, the ‘Braavoo Project’ saw the development of a floating laboratory, installed in a small autonomous catamaran controlled remotely, whose analytical results are sent to a central data collection. The measuring station integrates three different types of sensors: optical technology immunosensors, sensors for the detection of compounds such as mercury and algae sensors.

Conclusions

Increased demand for smaller more advanced electronic devices has driven advances on all levels. Global innovation in production processes has also boosted capability of micro and nanoelectronic systems. While engineering advances have provided the basis for chips not only containing electronic components, but also integrating mechanisms for sensing applications, resulting in a fusion between electronics and mechanics. This has combined to provide a host of opportunities from which the marine field can benefit.

The practice of implementing MEMS sensors in small electronic devices has provided a gateway for the development of embedded electronic systems for specific applications including navigation, detection, monitoring and control. Meanwhile, from a manufacturing perspective the development of MEMS devices oriented towards mass production, ensures low or moderate development costs, requiring lower levels of investment.

MEMS has further enabled specific electronic systems to be developed enhancing business models and production schemes oriented towards remote or autonomous management - a key aspect for the profitability of many possible operations in the marine field.

Leading producers of electronics worldwide have spent many years developing MEMS, carrying out research, production and commercial activity, ensuring a high degree of maturity across many applications. Electronics in general and MEMS in particular will enter a turning point in the coming years driven by advances in current technology including silicon semiconductors and possible progression towards new semiconductors or alternatives with greater capacity.

For more information on the KETmaritime project visit the website www.ketmaritime.eu phone +351 253 140 112 email Ana Vila on Ana.Vila@inl.int

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Project Partners:

Notes to editors:

KETmaritime is a €1million project that aims to transfer Key Enabling Technologies (KETs) to the Maritime Industries of the Atlantic Area. Focused on building a cooperative network that stimulates innovation and competitiveness, the project embraces the challenge of increasing the capabilities, skills and knowledge on KETs in an integrated and cross-national approach. The consortium brings together seven partners from five countries that, under the framework of the project, work closely with industries and businesses. The ultimate goal is to bring to market new processes, products and services. Partners in the consortium include French multidisciplinary research laboratory CIMAP (CEA group), Portuguese maritime economy cluster Fórum Oceano and Spanish industrial design centre IDONIAL. Ireland's national centre for marine and renewable energy MaREI and UK marine cluster organisation Marine South East are delivering further support, alongside Spanish non-profit research association AIMEN. KETmaritime is a project funded by the Interreg Atlantic Area Program, supported by the European Regional Development Fund.