High-end Inertial Sensors for Defense, Aerospace, and Industrial Applications
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COMPANIES CITED

OBJECTIVES OF THE REPORT

Provide a clear understanding of applications and related technologies.

Ecosystem identification and analysis:
- Determine applications range
- Technical market segmentation
- Economic requirements by segment
- Key players by market and analysis
- Market size and market forecast in $M and Munits

Analysis and description of market and technologies involved:
- Major actors on a global basis
- Detailed applications per market segment
- Technology identification for different products and processes
- Competing technologies
- Main technical challenges
The objectives of this report are the following:

To provide market data on high performance MEMS gyrosopes and gyroscope-based systems (gyro assemblies, IMUs, INS...):
- Key market metrics and dynamics
  - Unit shipments and revenue by type of sensor
  - Average selling price analysis and expected evolution
  - Market share for each category of application, technology and performance grade

To provide application focus on key existing markets and most promising emerging ones:
- Functions that are used, critical specification requirements, level of assembly and technology choices
- What are the major drivers? What will the market look like in 2022?

To provide an analysis on the major technology trends:
- Evolution expected for the current technologies: level of performance, price....
- Insight about emerging technologies: AO/Cold atom, NMR gyros....

To provide a deep understanding of inertial sensor value chain, infrastructure & players for the inertial business:
- Extensive list of sensor manufacturers worldwide and their technology offer
- List of key integrators worldwide
- Industrial chain information for each application: who supplies to whom
WHO SHOULD BE INTERESTED IN THIS REPORT?

High-performance accelerometers and gyroscope suppliers

- Understand the system level technology trends and requirements for each application
- Evaluate market potential for your components depending on performance and technology
- Understand the differentiated value of your products and technologies
- Identify new business opportunities and partners
- Monitor and benchmark your competitor’s advancements

IMU module and AHRS/INS suppliers

- Evaluate the market potential of your product portfolio
- Define diversification strategies on new applications
- Find the best technologies to integrate and the best suppliers depending on your target markets
- Identify new business opportunities and partners
- Have an exhaustive analysis of the competition on a broad range of IMU field

Material supplier, manufacturing service companies

- Spot new business opportunities and prospects
- Understand the level of activity of your customers
- Understand what are the applications that will drive the volumes in 2017

Integrators of inertial solutions, government agencies

- Find the best technologies to integrate and the best suppliers depending on your target markets
- Understand what will be the future applications to develop and benefit from the recent advances in inertial technologies
- Define technology roadmap / evaluate the benefits of using new technologies in end systems, design architectures for the next generation of systems
- Screen potential new suppliers able to provide new functionalities, or cost and size savings

R&D centers

- Evaluate market potential of future technologies and products for new applicative markets
- Identify the best candidates for technology transfer

Financial & strategic investors

- Understand the structure and value chain of the high-end inertial industry
- Estimate the potential of new technologies (tactical/inertial navigation MEMS, navigation-grade HRG…)
- Get the list of main key players and emerging start-ups of this industry worldwide
Yole's market forecast model is based on the following elementary structured blocks:
INTRODUCTION

2017 High End Inertial Sensors Industry

This report is an update of Yole’s best-selling “IMU Markets” report, which was first released in 2008. This latest edition is an updated version with some major changes since the last edition:

- The market is quantified for each gyroscope technology, and each company’s yearly shipments are estimated.
- Market metrics are provided for each grade of gyroscopes: each application is positioned according to performance level and corresponding market size.
- Applications are described in a synthetic way in order to provide rapid access to key information (functions, specification, technical solution, geography, trends, and market evolution) and graphical representation of the industrial chain.
- Software, Kalman filters and cost analysis have been investigated more deeply.

This report combines the best of Yole’s knowledge in the high-performance inertial sensor industry. Yole regularly participates in industry conferences and tradeshows worldwide, and has close relations with most market leaders. This report’s data has been validated by industry experts. This report synthetizes the status of the 2017 inertial sensor industry in a thorough manner.
SCOPE OF THE REPORT

Accelerometer, gyroscope, IMU and INS

**Accelerometer**
An accelerometer is a device that measures proper acceleration, which is the acceleration it experiences relative to movement or freefall.

**Gyroscope**
A gyroscope is a device that measures the changes in linear- or angular momentum/angular rate. The primary measuring magnitude of a gyro is always an angular speed.

**IMU**
An IMU (Inertial Measurement Unit) is a combination of multiple accelerometers and gyroscopes axis. Traditionally, an IMU is built with 3-axis accelerometer and 3-axis gyroscope to measure an absolute spatial displacement.

**INS**
An INS (Inertial Navigation System) is a system integrating an Inertial Measurement Unit combined with a GPS/GNSS/GLONASS chip and computational skills.
REPORT SCOPE

What you will find in the report...

Technology
- Accelerometer
- Gyroscope
- IMU
- INS

Markets
- Industrial
- Aerospace
- Military/Defense

Applications
- Agriculture
- AUVs
- Freight transport ship
- High speed train
- Inclinometers
- Oil drilling heads
- ROV
- Satcom antenna stab
- Stabilization of optical systems
- Survey instruments
- UGVs
- Vibration monitoring
- Business Jets
- Civil aircraft
- Civil helicopters
- Civil and paramilitary UAVs
- General aviation
- Satellites
- Space crafts & rockets
- Defense ships
- Defense transport aircraft
- Defense UAVs
- Guided munitions
- Soldier navigation
- LAV/Artillery Guns
- MAV/Tanks
- Military & special mission helicopters
- Military fighters
- Military submarines
- Nuclear missiles
- Short, medium and long range missiles
...

Trends & players
- Trends
- Players and ranking

Forecasts
- Forecasts
- Units
- $US Dollar
« High-performance » inertial sensors

→ This refers to the applications: we take into account all the inertial sensors except the consumer / mobile and the automotive applications

We take into account industrial, aerospace, defense applications (even industrial applications are considered as “high-performance” applications, as opposed to consumer ones)

In some cases: « consumer-grade » MEMS gyroscopes (for instance few °/s bias stability) are used in industrial applications → this is part of the report

To simplify representation, performance has been divided in 4 parts:

The only parameter which is considered is the bias stability

<table>
<thead>
<tr>
<th>Gyroscope</th>
<th>Corresponding Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Run (for industrial / tactical)</td>
<td>Industrial</td>
</tr>
<tr>
<td>or day to day (for navigation / strategic)</td>
<td></td>
</tr>
<tr>
<td>Bias Stability</td>
<td></td>
</tr>
</tbody>
</table>

- **100°/h**
- **5°/h**
- **1°/h**
- **0.5°/h**
- **0.1°/h**
- **0.05°/h**
- **0.01°/h**
- **0.0001°/h**

Day to day bias stability is considered for navigation grade, this is the most significant parameter in characterizing a navigation system

In-run bias stability is used for industrial and tactical grade because:

- In the past 20 years, MEMS have appeared and expressed performance in terms of « in-run » parameters
- Use of inertial sensors is now frequently used in conjunction with GPS, meaning that day-to-day bias repeatability in not significant anymore (for tactical / industrial grade)

Other parameters need to be considered as well: depending on the application parameters such as angular random walk or scale factor might be more important than just bias stability
High end applications have been split among 3 sectors:

- **Defense**
  - Defense ships
  - Defense transport aircraft
  - Defense UAVs
  - Guided munitions
  - LAV/Artillery Guns
  - MAV/Tanks
  - Military & special mission helicopters
  - Military fighters
  - Military submarines
  - Nuclear missiles
  - Short, medium and long range missiles
  - Soldier
  - ...

- **Commercial Aerospace**
  - Business Jets
  - Civil aircraft
  - Civil helicopters
  - Civil and paramilitary UAVs
  - General aviation
  - Satellites
  - Spacecrafts & rockets
  - ...

- **Industrial, Civil Naval and Offshore**
  - Agriculture
  - AUVs
  - Freighter transport ship
  - High speed train
  - Inclinometers
  - Oil drilling heads
  - ROV
  - Satcom antenna stab
  - Stabilization of optical systems
  - Survey instruments
  - UAVs
  - UGVs
  - Vibration monitoring
  - ...

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The diagram illustrates the high-end inertial market, showing the distribution of applications across different sectors.
DEFENSE, COMMERCIAL AEROSPACE AND INDUSTRY ARE BACK IN BUSINESS

Military / Defense
+ 4%
CAGR 2017-2022
~$1,100 M
HE Inertial Market Value

Commercial Aerospace
+ 5%
CAGR 2017-2022
~$1,000 M
HE Inertial Market Value

Naval/Offshore / Industrial
+ 5%
CAGR 2017-2022
~$900 M
HE Inertial Market Value

Emerging Applications
+ 22%
CAGR 2017-2022
~$50 M
HE Inertial Market Value

@2017 | www.yole.fr | High End Inertial Systems | Sample
REVENUE MARKET SHARES

2017 High-end inertial revenues market share - % and $M

~$3,100M
2017 High-end inertial (accelero, gyro, IMU, INS) volume market share - % and $M

>1.5 Mu
TECHNOLOGICAL MUSICAL CHAIRS

~$ 3,100 M

2017

~$ 3,900 M

2022

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MARITIME/OFFSHORE INDUSTRY TRENDS
# INDUSTRIAL / COMMERCIAL NAVAL / OFFSHORE APPLICATIONS

## Key Specifications by Application Category

<table>
<thead>
<tr>
<th>Application Category</th>
<th>Bias stab.</th>
<th>Gyro range</th>
<th>Scale factor</th>
<th>Noise</th>
<th>Other specs</th>
<th>Assembly level</th>
<th>Dominant technologies (in 2017)</th>
</tr>
</thead>
</table>
| Stabilization Systems | (XX°/h - XX°/s) | * (200°/s) | * (200°/s) | ⚫⚫⚫ | • Good vibration sensitivity: <0.1°/s/g on any axis  
  • Quick start-up time: <1s  
  • High bandwidth (up to 500MHz) | 2/3-axis assemblies  
  • AHRS | FOG  
  • MEMS  
  • DTG |
| GPS Aiding - Mobile Mapping | * (XX-XX°/h) | * (500°/s) | * (200°/s) | ⚫⚫⚫ | • Stable performance over temperature | IMU | Mostly RLG  
  • Few FOG and MEMS |
| ROVs / AUVs Navigation for Offshore | ⚫⚫⚫ (XX°/h) | (<200°/s) | * (500°/s) | ⚫⚫⚫ | • -55°C to 150°C and more temperature sustainability  
  • 1500g shock survivability  
  • High pressure sustainability  
  • Small size and power consumption (<0.5W)  
  • Large bandwidth: up to 2.7kHz  
  • Good vibration immunity | • IMU mostly  
  • AHRS | • Mostly DTG |
| Drilling | ⚫⚫⚫ (about XX°/h, sometimes up to 1°/h) | (200°/s) | ⚫⚫⚫ | • Rugged devices | 2/3-axis assemblies  
  • AHRS | • Mechanical gyros / DTG dominate  
  • Also FOG  
  • Few RLG |
| Commercial Ship Navigation / Gyrocompass | ⚫⚫⚫ (XX to XX°/h) | (200°/s) | ⚫⚫⚫ | • Small size (<4x6x2 inch³), low weight (<1lb), low power (to get 4hr battery life)  
  • Affordable  
  • Resistance to cold, extreme heat, moisture, shocks… | 2/3-axis assemblies and IMUs | |
| First Responder Systems | ⚫⚫⚫ (up to XX°/s) | (500°/s) | ⚫⚫⚫ | • Rugged devices | IMU | MEMS |

**Bias stability and noise are the most critical parameters for the very high end IMUs applications**

### Legend:
- ⚫Important parameter
- ⚫⚫⚫ Critical parameter

@2017 | www.yole.fr | High End Inertial Systems | Sample
GPS aiding is the largest market in value for the industrial segment with a gyro stability ranging from 5 to 0.05°/h.
STABILIZATION SYSTEMS

Application description

| Function | • Stabilization of moving Satcom and radio antennas (on ships, trains, road vehicles, aircraft), for stabilization and to keep pointing in the direction of the satellite signal  
• Stabilization of gimbals (cameras…)  
• Various other types of stabilization: marine vessels, drilling platform, personal transporter… |
| Key specifications | • Noise is critical  
• Bias stability: not important (varies between 0.1°/h and 5°/s → 1-10°/h if angles are needed, otherwise lower performance can be ok: only angular speed data is required)  
• Good vibration sensitivity: <0.1°/s/g on any axis  
• Low measurement range (200°/s max)  
• High bandwidth (up to 500MHz)  
• Quick start-up time: <1s |
| Inertial solution | • Mostly full AHRS system  
• Or gyro assembly: 2 or 3-axis → large market for FOG  
• Sometimes single axis gyro's (e.g. to detect 90° / 180° turns in some agriculture applications)  
• MEMS, FOG, and mechanical gyro's commonly used depending on the application (RLG: because of mechanical dither it cannot be used in applications requiring very quiet operation like stabilization of most optical seekers and navigation of torpedoes) |
| Technology trends | • Industrial-grade MEMS is sufficient for most antenna applications.  
• 2 types of applications: antenna tracking (need high performance) / platform stabilization for sonar or internet on train… (lower performance: can deviate)  
• Miniaturization → MEMS technology is growing. MEMS is increasingly common because this is a temperature controlled environment (→ not military specs) |
| Key gyro players | • Safran Sagem (Quapason), KVH (DSP 1500), SSS, NG, Honeywell, NG Litef, UTC / AIS Goodrich, ADI… |

Stabilization systems are mostly full AHRS systems. MEMS, FOG, and mechanical gyro's are commonly used. MEMS is growing because it is a temperature controlled environment.

SeaTel marine stabilized Satcom antenna

DSP1500FOG from KVH is used in gimbal stabilization systems
CONVERGENCES LEADING TO THE ROBOTICS REVOLUTION

Three industries are converging to spur the robotics revolution

Why now?

• Smartphones helped develop advanced microelectronic technologies at low cost

• The internet provides a communication/cloud computing infrastructure coupled with high demand for connected devices

• Autonomous vehicle R&D allows for high-priced technology testbeds fueled by car brands’ search for differentiation
AUTONOMOUS VEHICLES: THE DISRUPTION CASE

Two distinctive paths for autonomous vehicles

- Improvement of cars as we know
- Electronics Invades cars
- Electric car matures
- Automated driving
- New use cases

Disruption?

Below expectation “cars” fulfilling needs in a new plane of consumption

2020 should see the first implementation of autonomous vehicles

Acceleration: The speed of technology change doubles every technology shift

1880 80 years 1960 40 years 2000 20 years 2020 10 years 2030 5 years 2035
Growth is expected in all areas of the market.

LONG-TERM OPPORTUNITIES OF THE HIGH END INERTIAL MARKET

2017-2022 forecast

~$3.9B CAGR ~ +5%

~$3.1B

Total HE inertial industry
- Defense/Military
- Naval/Offshore/Industrial
- Commercial Aerospace
- Emerging applications

~$3.1B

$1,300M CAGR +4%

$1,200M CAGR +5%

$1,300M CAGR +5%

$1,000M

$1,100M CAGR +4%

$1,000M

$900M

$50M

$150M CAGR +22%

2017

2022

Growth is expected in all areas of the market.
Defense and commercial aerospace markets have always been the backbone of the high-end inertial system market, and that is still true today. The traditional markets, like defense, commercial aerospace and space applications, have returned to growth after a big slowdown from 2010-2015. For the last two years, the market has been evolving positively thanks to increasing geopolitical risks, and benefiting from the reinvigoration of the commercial aerospace business. And the end of the oil crisis in 2015, combined with increasing purchasing power coming from eastern regions, especially China, has definitely benefited this market. The space market is still evolving at its own pace, with the increasingly important robotic approach coming from players like SpaceX, Blue Origin enabling reusable rocket launchers, democratizing the space market.

In other words, the high-end inertial system market is recovering from a lean period that could bring it, in the long term, into a prosperous time with higher volumes. At long term, the market should be propelled by two major trends: the robotic approach and the growth of industrial applications. Yole Développement estimates that the high-end inertial system market has reached the $3B milestone in 2017. Defense makes up 36 % of this, with commercial aerospace comprising 33 %. Industrial, offshore and maritime applications account for the remaining 31 %. With a compound annual growth rate (CAGR) estimated to be 5% for the five next years, the high-end inertial system market is on a good track. The industry is now looking for emerging opportunities to sustain its growth, and this is what we highlight in this report.

RINg Laser GYroscopes (RLGs) are competing strongly against Fiber Optic Gyroscopes (FOGs) and HEMispherical Resonant Gyroscopes (HRG) on the low-end, silicon MEMS benefit from INDustrial OPPORTUNITIES and TESTING of EMERGING APPLICATIONS

For over 20 years, silicon MEMS technology has been predicted to fill the gap between other high-end inertial system technologies. This is now obviously happening, but at a slower pace than expected. Evolution of silicon MEMS technology opens new opportunities at the lower end of the market, above 1°/hour bias stability, fueling applications like industrial monitoring.
Although silicon MEMS is pushing FOG technology out of low-end applications, it is still too immature to conquer applications that require bias stability below 1°/hour. FOG technology players such as KVH and iXBlue are instead trying to expand their capabilities to compete against RLG technology and silicon MEMS. An internal battle is happening in the FOG technology with open-loop and close-loop approach RLG technology is also being challenged at higher performance levels by HRG technology. HRG has achieved huge improvements in recent years thanks to the investments from two major players in the field, Northrop Grumman and Safran. If cost-effectiveness and production complexity issues with this technology are solved quickly in the coming years, it could seriously impact the RLG business. However the necessary steps will probably take time. Know-how and involvedness of HRG technology also impose a high entry barrier to any other companies. Honeywell still dominates the RLG market thanks to its reliable, cost-effective technology that perfectly fits technology requirements for the commercial aerospace business. Analog Devices, Inc. (ADI) and Silicon Sensing Systems dominate the MEMS segment addressing low-end industrial applications thanks to a wide product offering.

Verticalization of the market is still going on and is a key element in the race to get a competitive advantage, because it allows optimization and cost reduction. This requires mastering manufacturing entire systems, including accelerometer, gyroscope, application specific integrated circuits (ASICs) and software. This report describes the applications, technologies, and players associated with high-end inertial systems’ impending changes.

A TRADITIONAL MARKET DOMINATED BY GIANTS, BUT LOTS OF OPPORTUNITIES ARE APPEARING FOR EVERYONE

Among all applications, emerging ones identified in our last report are still gaining interest. These new applications span from robotics to industrial automation, autonomous cars, ships, planes and drones, structure monitoring, space conquest with reusable rockets and microsatellites. Such uses are expected to add growth. Most players are looking at these new opportunities, partnering with end-users to understand the needs and requirements to adapt the specifications of high-end inertial systems in term of accuracy, volume, shielding and cost. Currently, most of those applications are in R&D and prototyping phases, but requirements and standards are being defined today, and should impact the market for years. The race into the robotic era is under way and many sensors are in competition. Inertial systems have advantages, and will definitely take part in this revolution that will have a deep impact across the whole industry.
This report provides a detailed vision of the industry landscape, as well as the applications trends and shipments forecasts for high-end inertial systems for traditional and emerging applications, whether covered by International Traffic in Arms Regulations (ITAR) or not.

COMPANIES CITED IN THE REPORT (non exhaustive list)

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