

Ultra-accurate inertial navigation systems make innovative use of high-performance accelerometers



Image courtesy of Aeroscout

Oxford Technical Solutions (OxTS) manufacture extremely accurate inertial navigation systems, such as the device carried by this unmanned aerial vehicle. Providing very precise measurements of position, heading, roll and pitch, they are ideal for applications such as aerial mapping and photogrammetry.

Accurately measure position, heading, roll and pitch

Near the engineering design centre of Oxford Technical Solutions (OxTS) a UK-based manufacturer of ultra-high performance inertial navigation systems (INS) is a disused airfield. Its wide runways are the perfect location for testing its products, which are widely used by automotive manufacturers. Not that the positioning systems made by OxTS can be compared to a conventional car's satellite navigation system, which can typically narrow a vehicle's position down to an area approximately the size of a small house's floor area. The INS manufactured by OxTS at its headquarters in Upper Heyford, Oxfordshire do rather better than this: they can pinpoint an object's position on the surface of the earth to an area the size of a postage stamp.

These ultra-accurate INS are used in a wide variety of applications requiring very precise measurements of position, heading, and roll and pitch, such as performance testing and validation of cars and motorbikes, surveying and mapping, aerial photogrammetry, avionics, disaster site monitoring and camera stabilisation.

About the project

In developing its latest product, the xNAV series, the design team at OxTS was set the problem of creating a smaller, lighter and cheaper version of its flagship, high-end RT series INS, while maintaining performance almost as extreme as that of the RT. As part of the development process, the choice of accelerometer in the xNAV - a device from specialist MEMS manufacturer Colibrys - required an innovative and precisely engineered technique for error compensation. And as this article shows, this optimisation benefited from the support provided by technical distributor Acal BFi.



Part of the technology behind the xNAV series from Oxford Technical Solutions (OxTS) relies on high performance, small footprint accelerometers from Colibrys.

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The application of high-performance INS

The value of the INS manufactured by OxTS is in their extremely high accuracy. A single-antenna GPS navigation system of the kind found in a modern car can typically achieve horizontal positioning accuracy of 10m in good conditions – that is, in open space, with a stable GPS signal. In difficult conditions for satellite navigation, such as a built-up urban area, this accuracy figure typically rises to 20-40m.

By contrast, OxTS's flagship RT series is rated for horizontal positioning accuracy as high as 1cm. The accuracy of the other parameters – heading, roll and pitch – also measured by the INS reaches similarly high levels.

In order to achieve this extraordinarily high performance, the high-end RT series is designed without compromise. At its heart are best-in-class single-axis accelerometers, gyroscopes and GNSS (Global Navigation Satellite System) receivers the cost of which reflects their high performance. Size and weight reduction is also no part of the design brief: when mounted inside a prototype car design for performance testing, or in a land-based survey vehicle, the 234mm x 120mm 80mm RT series, weighing in at 2.4kg, is easily accommodated.

The extremely accurate, real-time measurements of position, heading, pitch and roll made by the RT series enable manufacturers in the automotive industry to analyse vehicle dynamics with great precision, compare the performance of different tyre designs, validate the operation of Advanced Driver Assistance Systems (ADAS) and control robotic or 'self-driving' vehicles.

The INS products from OxTS, then, have many uses when the relative or absolute position, attitude and heading of a moving object needs to be known with very great accuracy.



Demand for smaller, lighter INS products

In some applications, however, the size, weight or cost of the RT series products makes them unsuitable. This applies, in particular, to aerial applications, including avionics and Unmanned Aerial Vehicles (UAVs). Small robotic test platforms used in automotive testing also call for a smaller, lighter INS than the RT series.

This demand for size and cost reduction led to the development of the xNAV series. The OxTS design team, however, still had to meet tough targets for the accuracy of the device's measurements, despite using markedly cheaper components. The single-axis accelerometers inside the xNAV, for instance – a MEMS sensor product from specialist manufacturer Colibrys – are some five times cheaper than those in the RT series. Yet while the highest-rated RT series product can achieve measurements of velocity accurate to 0.05km/h, the xNAV's accuracy is still an outstanding 0.1km/h.

The ability to measure velocity and heading with high accuracy enables the xNAV to achieve very low drift – the non-linearity in the positioning measurement that occurs after the GPS signal is lost. In this condition, the INS will calculate the distance and direction of travel based on the outputs from the accelerometers and gyroscope. In automotive applications, these measurements may be correlated (in post-processing) with inputs from rotary sensors on the vehicle's wheels. In the xNAV series, this drift value is specified at 0.95m after 60s of travel without GPS inputs, and with the benefit of odometer corrections.

Even when using very much cheaper accelerometers, then, the xNAV's designers were able to maintain accuracy of inertial measurements in the laboratory close to those of the high-end RT series. But the use cases for the xNAV, such as position and heading measurements in UAVs, involve operation in real-world conditions, and in particular at real-world ambient temperatures. And while the Colibrys accelerometer is capable of high accuracy in stable, laboratory conditions, its temperature drift is large enough to impair the performance of the xNAV if not compensated.

The xNAV fills the gap between light-weight inertial systems that are not accurate enough, and accurate inertial systems that are not small enough.

Unique calibration technology

As the OxTS design team worked out a way to optimise system performance across the xNAV series' specified operating temperature range (-40°C to 70°C), it became necessary to investigate and clarify in unusual detail the operation and characteristics of the Colibrys sensor. And here, the assistance and technical expertise of the applications engineers at Acal BFi were invaluable. Acal BFi, the sole UK distributor for Colibrys, is a value-added supplier of electronics and optoelectronics components and systems. Its technical service to OEMs is underpinned by the expertise of its Europe-wide team of field applications engineers, experts with in-depth knowledge of the components that Acal BFi supplies and the applications in which they may be used.

During the development of the xNAV series, Acal BFi was able to act as an information bridge between OxTS and the component manufacturer. Because of the extreme nature of OxTS's performance requirements, many of the questions that it asked about the accelerometer had never before been put to Colibrys. As a low-volume manufacturer, OxTS could not form a direct relationship with Colibrys. By acting as an extension of the OxTS design team, Acal BFi was able to acquire for its customer the detailed and unusual information from Colibrys that OxTS could not have got unaided.

This information helped OxTS to develop a highly effective method for compensating for the temperature drift of the Colibrys accelerometer, enabling it to specify a linear accuracy rating for the xNAV's inertial measurements across the entire operating temperature range. At its engineering design centre in Oxfordshire, OxTS has built a 'calibration table', a stable platform on which every assembled xNAV unit may be mounted and rotated in three dimensions. The platform is housed in a closed chamber into which hot and cold air may be pumped.

By capturing the outputs from the three accelerometers inside each xNAV at various temperatures, OxTS is able to calibrate each manufactured unit to its reference standard. By applying a software compensation algorithm, implemented in the device's on-board applications processor, OxTS is able to guarantee the linearity of the device's inertial measurements.

This unique technology for calibrating performance over a population of production units, and over temperature, has been crucial to the success of the xNAV design, enabling it to deliver ultra-high performance while using a compact, mid-range MEMS accelerometer characterised by some integral non-linearity.



Each xNAV contains three MS9000 series accelerometers from Colibrys.

MEMS accelerometers finding new applications

The Colibrys accelerometers supplied by Acal BFi provide for high performance, high vibration resistance and a small board footprint. Thanks to the engineering innovations of OxTS, the outputs from the sensors have been optimised in the xNAV for extreme high performance, but the high native accuracy of Colibrys accelerometers makes them suitable for a very wide range of applications requiring positioning and inertial motion sensing. In any such application, the technical expertise and close customer collaboration offered by Acal BFi's applications engineers promises to make the development process as successful as that of the remarkable xNAV.

For more information on the Colibrys sensor range, visit www.acalbfi.com

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