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Performance Thresholds for Application of MEMS Inertial Sensors in Space.

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Abstract

We review types of inertial sensors available and current usage of inertial sensors in space and the performance requirements for these applications. We then assess the performance available from MEMS (Micro-Electro-Mechanical Systems) devices, both in the near and far term. Opportunities for the application of these devices are then identified. A key point is that although the performance available from MEMS inertial sensors is significantly lower than that achieved by existing macroscopic devices (at least in the near term), the low cost, size and power of the MEMS devices opens up a number of applications. In particular, we show that there are substantial benefits to using MEMS devices to provide vibration, and, for some missions, attitude sensing. In addition, augmentation for GPS navigation systems holds much promise.

Introduction

The prospect of the availability of very small, very low cost and low power inertial sensors opens up the possibility of a number of applications for these devices in space. The viability of these applications will clearly depend on the performance of the MEMS devices. The main performance measures we shall discuss are bias stability (drift rate) and radiation hardness. Depending on the application, other performance measures may be more relevant, however these represent key issues for space. In general, the time scales of space vehicle maneuvers are relatively slow compared with those of terrestrial vehicles, justifying the interest in drift rate. The space radiation environment is far more hostile than most terrestrial environments, so that some degree of radiation hardening is required, even for low altitude orbits.

Since the size of the space market is very small compared with many terrestrial markets, most MEMS devices are being developed with an eye toward terrestrial applications (e.g. automotive braking controls). It is of value to assess the extent to which such devices can be adapted to space applications. Alternatively, special devices will have to be developed for space (with a corresponding cost impact).

Current uses of inertial sensors in space

The following table summarizes the main current applications of inertial instruments in space, including typical performance requirements.

Table 1

Current Uses of Gyros in Space

Application	Drift Rate
Launch Vehicles	0.1°/hr
Spacecraft delta-V	0.1°/hr
Spacecraft Pointing	0.01°/hr

Attributes of typical instruments currently in use to meet these requirements are listed in the following table

Table 2

Typical Space Gyros (IMUs)

Type	Weight	Power
SKIRU DII	28 lb	15 - 26 W
Honeywell YG9666	3.6 lb	17.5 W
Delco HRG TNS 311	3.5 lb	10 W

The cost, weight and power requirements of these devices are high enough that their use (particularly in situations where redundancy is required) represents a significant impact on the cost of a program. In many low cost programs, a minimal set of attitude determination instruments is used. Often this does not include a gyro. In many situations this can result in compromised performance, or excessive operational costs later in the mission in the event of component failures or anomalies. Some examples are cited in the following table:

Table 3

Anomalies indicating desirability of MEMS back-up

Vehicle	Anomaly	MEMS could have simplified..
STEP M0	Gyro loss	- delta-V maneuvers - normal mode (reconfiguration from 3-axis to momentum bias was required)
Classified	flat spin	Recovery from flat spin

The desirability of being able to add components to achieve enhanced performance, flexibility or redundancy is clear. We now turn to the question of whether, or to what extent, MEMS devices can fill this need.

Current and near term performance from MEMS devices

The following table summarizes the performance available from experimental units fabricated at C.S.Draper Laboratories.

Table 4

Performance of current MEMS gyros

Attribute	Performance
Angular random walk	0.037 deg/rt.hr.
Scale factor stability	100-150 ppm
Drift rate (60 Hz B/W)	24 deg/hr
Drift rate (0.1 Hz B/W)	1 deg/hr

Mid-term performance (18-24 month delivery) would be of the order:

Angular random walk	0.008 deg/rt.hr.
Scale factor stability	50 ppm
Drift rate (60 Hz B/W)	6 deg/hr
Drift rate (0.1 Hz B/W)	0.25 deg/hr

Long term (3+ years) these numbers may come down to 0.001, 10+, 1 and 0.024 respectively.

The cost of these items depends on the time scale of delivery and on the packaging. Using hybrid electronics (about a 4" x 4" board) and a 6-12 month delivery time, would cost around \$300-\$500K. With the electronics in an ASIC, the time scale would stretch by about 6 months, and the cost would go up by about \$200K. The size of the ASIC system would be less than 1" square. Power and weight would be of the order of 0.25W and 5 grams respectively. In the long term, costs would come down substantially, although the actual numbers would depend on a number of details, including the emphasis placed on the needs of the space community when production units are developed. High production units (e.g. for automotive use) would be very low cost. However, the actual cost to integration into a space vehicle would include whatever modifications would be required.

When we compare the near term performance numbers with the requirements in Table 1, we note that in general the MEMS units cannot be used as direct substitutes for current devices. We must therefore either determine when (or if) the performance of the MEMS devices will reach this level, or we must look into the possibility of finding new or modified applications. We shall concentrate on the latter.

From the standpoint of technological limitations, the MEMS devices have relatively high drift rates, and therefore must be used in "short time scale" applications. The need for radiation hardness, although critical from a practical standpoint, is not driven by a lack of technological capability as much as by a lack of need in the main markets driving the development of MEMS inertial sensors. The vulnerability to radiation occurs in the electronics (FETs etc., used in the preamplifiers and signal processing circuits), not in the MEMS devices themselves.

The following table summarizes a number of applications in which the time scale is short enough to permit the effective use of MEMS sensors.

Table 5

Short time-scale applications in space

Launch vehicles

- Augment GPS (esp. for range safety)
- Environment monitoring

Spacecraft

- Maneuvers
- Detumble (e.g., Acquisition, Safehold Modes)
- Vibration Control (e.g., Large Structures, Deployables)
- Vibration Monitoring (e.g., fault detection on wheel bearings)

In addition to these applications, which would improve the performance and redundancy of current types of satellites, there is the question of future "nanosatellites". In these systems the whole satellite will be built on a "chip" (or at least some wafers). For such applications, the use of MEMS will be mandatory. The necessary performance could be acquired by using the MEMS devices to augment a long time scale sensor (e.g., a miniature star sensor).

Conclusions

There are a number of applications which could benefit from the availability of space hardened MEMS gyros (and accelerometers) - even with the performance limitations currently associated with these devices.

Bibliography

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Information on the Draper MEMS gyros was from J. Gilmore (verbal communication).