Micro-Guidance and Control Technology Overview

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Abstract

This paper gives an overview of micro-guidance and control technologies and in the process previews of some of the technologies, users and systems issues presented in the guidance and control session at the workshop. We first present a discussion of the advantages of using *micro* guidance and control components and then detail six micro-guidance and control thrusts that could have a revolutionary impact on space missions and systems. Specific technologies emerging in the micro-guidance and control field will be examined. These technologies fall into two broad categories: micro-attitude determination (inertial and celestial) and micro-actuation, control and sensing. Finally, the scope of the workshop's guidance and control panel will be presented.

1 Introduction

For this paper we define micro-guidance and control technology as consisting of two items. First, it includes micro-miniaturized guidance and control components and subsystems (sensors, actuators and control electronics). Second, it includes micro-guidance and control architectures realized by integration of micro-machined devices and on-chip VLSI circuits with guidance and control functions.

As with many microtechnologies, micro-guidance and control components and technologies have numerous advantages over their larger counterparts. These advantages include lower mass, volume and power consumption than components used on today's spacecraft. With solid state reliability, there should be lower risk and more robustness to temperature and vibrations. Lower costs are expected with fewer hands needed to handle the devices and with cost saving potentials inherent in batch processing technologies. Some microsystems could be more capable than today's larger systems because the decreased mass, volume and power consumption would allow redundancy or even massive redundancy of components.

In the Guidance and Control Section at Jet Propulsion Laboratory, we believe that micro-guidance and control technologies can have a revolutionary impact on space missions and systems via innovative work in six thrust areas:

1. Massively distributed microsensing for system identification and control to enable space interferometers and large reflectors.
2. Light powered remote processing networks for guidance and control microsensing to enable viable distributed identification and control architectures needed to support item 1.
3. Micro-guidance and control components for microspacecraft and microrovers to enable essential subsystem functions. These components include micro sun sensors, encoders, star trackers and motors.
4. A six degree of freedom (acceleration and attitude) micro inertial measurement unit for microspacecraft and microrovers to enable guidance

and control navigation functions.

5. Actively controlled micromachined deformable mirrors for adaptive reflee.tors to provide optical performance not presently feasible.
6. Embedded health sensing for guidance and control effectors to monitor and manage mission effectiveness and lifetime.

Some of the emerging micro-guidance and control technologies that will support these thrusts are described in the following section.

2 Micro-Guidance and Control Technologies

This section will present an overview of present and emerging micro-guidance and control technologies from NASA, private industry and academia [1]. Some systems and users issues will be considered as well. The first broad area of technology to be covered is attitude determination, both celestial and inertial. This is an area where most of the advantages of microtechnologies will hold, with the possible exception of more capability. Microgyroscopes, for example, tend to have much higher drift rates than larger devices flying on today's spacecraft. The second broad area covered will be micro-actuation, control and sensing.

2.1 Micro-Attitude Determination, Inertial and Celestial

Microfabricated gyroscopes and accelerometers are now being developed at the Charles Stark Draper Laboratory, Cambridge, Massachusetts, using batch processing techniques such as photolithography, diffusion and etching to carve mechanical parts, Draper is working on three distinct devices:

1. Gimballed, vibrating gyroscopes and force rebalance accelerometers constructed from bulk silicon
2. Polysilicon surface machined tuning fork gyroscopes
3. Quartz resonant accelerometers and gyroscopes

One reason Draper is pursuing three separate technologies is in part to lessen the risks associated with emerging technologies.

Sat con Technology Corporation, Cambridge, Massachusetts, is also working 011 microgyroscopes, in this case electrostatically suspended micromechanical rate gyroscopes based on variable capacitance motors developed at M I'J'. The device resembles an electrically suspended disk and is controlled to provide rate information. Surface micromachining lithographic techniques are the proposed fabrication processes, and the eventual goal is to develop a microgyroscope suspended in all six degrees of freedom.

Work on gyroscopes is also being done overseas by GEC Ferranti in Edinburgh, Scotland, which is fabricating piezo-electric vibratory angular rate transducers (gyroscopes). They make use of a cylinder of radially poled piezo-electric ceramic, metallized inside and out. The outside is divided into eight electrodes and the inside is earthed. The cylinder vibrates in one of two modes, with rotation causing a coupling of these modes which can be detected. With this kind of microdevice we obtain the kinds of benefits listed earlier - decreases in size, mass, power consumption and cost with increased reliability.

At the J 1'1, Microdevices Laboratory, novel sensor technologies are being developed for micro accelerometes and seismometers. Researchers at the Microdevices Laboratory have made the crucial observation that compactness of devices leads to fundamental physical problems associated with sensor sensitivity and noise, including thermal noise. Some recent devices developed have been based 011 electron tunneling and have resulted in ultrahigh sensitivity microaccelerometers with major reductions in mass, volume and power.

The final emerging technology in micro-attitude determination has to do with celestial sensing. OCA (optical Corporation of America) Applied Optics in Garden Grove, California, has developed a suite of miniature wide field of view star tracker cameras. The original device was developed jointly with Lawrence Livermore National laboratory for Brilliant Pebbles and has a field of view of 60 degrees. A follow-on camera has a 25 degree field of view and features a dual-redundant camera with a 100 microradian accuracy, 3 0, and is fully autonomous. These devices are also noted for low cost, mass and power.

2.2 Micro-Actuation, Control and Sensing

Microtechnologies have also been applied to the actuation, control and sensing functions that are important to spacecraft and space guidance and control subsystems. Recently there has been joint work between JPL and UCLA on micromachined deformable mirrors which could be used on large space interferometers to compensate for distortions in elements of the optical train and in the instrument's field of view. The pixelated capacitive linear actuator is the key microtechnology needed to produce a highly pixelated mirror surface to be controlled. The actuators could be monolithically integrated with the mirror assembly. Research is also being done on the modeling and control of these devices.

Micromachined sensors are a rapidly developing microtechnology that could aid guidance and control systems. An example of this kind of technology, being developed at the Georgia Institute of Technology, Atlanta Georgia, involves epitaxial liftoff to fabricate thin-film, single crystal, optical quality semiconductor devices. The technique employs surface micromachining and epitaxial growth with sacrificial layers such as aluminum arsenide. Depositions of light emitting diodes have been made on micromachined movable platforms yielding microoptomechanical devices. Here the potential exists for integrated interferometric sensors and steerable and movable light sources.

From a systems and users perspective, the Johnson Space Center, Houston, Texas, and the Honeywell Systems and Research Center, Minneapolis, Minnesota, are examining how micromachined sensors could be used for vehicle health monitoring. The health monitoring task would include manned space vehicles. They have examined requirements that vehicle health monitoring places on micromachined sensors, including requirements on performance, size, mass and fault tolerance. The two centers are also grappling with the issue of how commerical and military sensors can be used to meet space systems requirements.

Some good overview work on micro-guidance and control technologies has been done in the JPL Guidance and Control Section. In particular they have noted that Lunar and Mars explorers, space based interferometers and remote sensing platforms, whether Earth orbiting or planetary flyby or orbiting, could benefit greatly from microelectromechanical technology. They believe that the synergistic use of microminiature sensors, VLSI microelectronics and fiber optic networks will give rise to new guidance, navigation and control capabilities. Six microtechnology products or thrusts have been identified that could enable new guidance and control subsystems. These were listed in the introductory section.

3 Guidance and Control Panel Scope

The Guidance and Control panel will be considering the technologies presented in the previous section as it charts a course for micro-guidance and Control technology development. At the workshop, the panel will focus on emerging micro-guidance and control technologies, users and systems issues with the following emphases:

- Microdevice guidance and control subsystems for spacecraft with emphasis on component technology, attitude and articulation control and health monitoring and recovery.

    microsensor and microactuator design including electronics, power and information processing

  - fabrication technologies including silicon processing, micromachining and tunneling technology.
  - distributed architecture issues including data handling, power transmission and microsensing.

- Platform applications will include
  - shape control for multi-use vehicles and large instruments like radiometers, and vehicle guidance, navigation and control
  - system identification, health monitoring and remote sensing applications.

- Science mission applications will include system identification, optical figure control for ground/spaceborne telescopes and interferometers, and instrument pointing/sensing/isolation.

4 Conclusion

In this paper we have briefly reviewed the advantages of using *micro*-guidance and control components and architectures and listed six microtechnology thrusts in guidance and control that could have a revolutionary impact on spacecraft and space missions. We also reviewed some of the emerging micro-guidance and control technologies. These technologies included micro-attitude determination, inertial and celestial, and micro-actuation, control and sensin . Finally, we included the guidance and control panel scope that will be used to direct the efforts of the panel as it creates a technology development plan.

References

[1] Workshop on Microtechnologies and Applications to Space Systems, Workshop Abstracts, Guidance and Control Panel Parallel Session, May 27 and 28, 1992, Jet Propulsion Laboratory, Pasadena, CA.