WORKSHOP PROCEEDINGS: MICROTECHNOLOGIES AND APPLJCATIONS 'I'() SPACE SYSTEMS

ABSTRACT

Study Coordinator and Report Editor: B.A. Wilson, J]'I.
Workshop Chairs: F.Y. Hadaegh, W.J. Kaiser ancl B.A. Wilson, JPL

During FY'92, the NASA Code RS System Analysis RTOP funded a study to evaluate the potential impact of emerging microtechnologies on future space missions. As part of this stud y, a workshop, "Microtechnologies and Applications to Space Systems" was held May 27-29th, 1992, in Pasadena, CA, This volume serves as the Proceedings of this workshop. It contains the manuscripts provided by plenary and parallel session presenters, and summary reports generated from this material and from information presented during the panel discussions. Where manuscripts were not provided, extended abstracts, if available, have been included. The order of the papers follows the original workshop agenda.

Micro-Software for Micro-Robots

David P. Miller*
MIT AI Lab
545 Technology Square
Cambridge, MA 02139

Abstract

Microtechnology has successfully reduced the size of processors, sensors, and actuators orders of magnitude from what they were a few years ago. This has allowed researchers to build a new breed of robots massing only a few kilograms (or in some instances grams) that have all of their functions onboard. This is quite an accomplishment compared to robots of only a decade ago whose cameras or computer would outweigh dozens of these current "micro-robots." Not to be outdone, software engineers and AI researchers have produced new robot programs that are more capable and orders of magnitude larger than the robot software that was available a few years ago. Despite the fact that today's micro-processors are more capable than yesterday's supercomputers, this new software will not fit on today's small robots.

It takes energy to store data in memory or to perform a computer operation. The more operations and data storage, the more energy is needed, Robots must operate in the world, in time to react to changes and events in their environment. The faster the robot needs to operate, the faster it needs to process its program, and the more power it needs for computation. The more power it needs for computation, the larger the power and thermal systems it needs to carry, which mean the larger (and more massive) its structure needs to be. The larger heavier its structure, the larger its actuators need to be, the larger its actuators, the more power they require. For space applications, the amount of software to be processed per second on a robot can have significant impact on the launch mass of the system.

Fortunately, AI research has also produced what has become known as "behavior control programming." Behavior control is an alternative method of programming robots (particularly mobile robots) which requires orders of magnitude less processing than traditional sense-plan-act control of these robots.

This task will review the current state-of-the-art in behavior control. Examples of its capabilities and limitations will be given. The role of behavior control in space robotics will also be explored.

*On leave until 10/92 from the Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109

Note: This is page 69 in final version of JPL Publ. 93-8.

WORKSHOP PROCEEDINGS: MICROTECHNOLOGIES ANI) APPLICATIONS TO SPACE SYSTEMS

FOREWORD

Study Coordinator and Report Editor: B.A. Wilson, JPL
Workshop Chairs: F.Y. Hadaegh, W.J. Kaiser and B.A. Wilson, JPL

During FY'92, the NASA Code RS System Analysis RTOP funded a study to evaluate the potential impact of emerging microtechnologies on future space missions. As part of this stud y, a workshop, "Microtechnologies and Applications to Space Systems" was held May 27-29th, 1992, in Pasadena, CA. There were three main goals of the workshop:

- provide a forum for the fruitful exchange Of ideas on emerging and future microtechnologies, and stimulate the development of a NASA-wide microtechnology community.
- Provide an overview of emerging microtechnology capabilities, and evaluate their potential for future NASA applications
- Identify important near-tern NASA applications of these emerging technologies, and develop an integrated technology development plan to meet these requirements by the target dates

Pre-workshop discussions involving JPL, LaRC, LeRC and GSFC personnel, as well as interactions with non-NASA funding agencies including NSF, SD], DARPA, AFOSR and the Gas Research institute, lead to the identification of six key applications areas. Panels were convened as part of the workshop to focus attention on these key areas:

Application Area	**Panel Chairs**
Science Instruments	Ben Clark (Martin Marietta), Gregg Vane (JPL)
Microrovers	Ken Gabriel (NRL), Subramani Venkataraman (JPL)
Guidance and Control	John DiBattista (NASA), Fred Hadaegh (JPL), Claude Keckler (LaRC)
Space Station, Shuttle and Propulsion	W.T. Powers (MSFC), Gerald Voecks (JPL)
Microspacecraft	Denis Connolly (LeRC), Ross Jones (JPL)
Microtechnologies of the Future	Frank Grunthaner (JPL), John Hines (ARC), Brent Mott (GSFC)

The charge of the first four panels was to evaluate the potential of emerging device concepts such as microsensors and actuators in their respective applications area. The Microspacecraft Panel had a somewhat different charter. They started with a first-generation microspacecraft defined as the "microtechnology" element, and examined the subsystem and integration requirements for a near-term implementation. Their charge was to identify areas requiring further development, regardless of the nature of the technologies involved, Finally, the Microtechnologies of the Future Panel attempted to identify microtechnology development areas of the future which offer the most revolutionary new possibilities for enhancing the science return of NASA space missions, Panel membership is detailed in the Appendix.

The three-and-a-half-day workshop consisted of a day and a half of plenary sessions, an afternoon of focused parallel sessions, and a third morning of panel discussions. 'l"he plenary session topics, listed below, were deemed relevant to all applications areas.

Plenary Session Topics	**Speakers**
Future Visions	Charles Elachi (JPL), George Hazelrigg (NSF), Kurt Petersen (Lucas NovaSensor)
Mission and Science Goals	Corinne Buoni (SAIC), Lonnie Lane (JPL), Paul Henry (JPL), Jim Randolph (NASA), Aldo Bordano (JSC)
Microtechnology Programs	Stephen Jacobsen (Univ. of Utah), Mick Blackledge (S1>1), Al Wheatley (DARPA), Dave Lavery (NASA), Ned Godshall (Sandia), Robert Barrington (Louisiana Tech, Univ.), Bill Kaiser (JPL), Richard White (UC Berkeley), Noel Macdonald (Cornell Univ.), Henry Guckel (Univ. of Wisconsin- Madison), Wilfrid Veldkamp (Lincoln Laboratory), Joseph Stetter (Transducer Research, Inc.)
Applications Overviews	Bill Trimmer (Princeton Univ.), Jan Iwanczyk (Xsirius, Inc.), Jim Tillman (Univ. of Washington), Ken Gabriel (NRL), Marc Madou (Teknekron), M.G. Littman (Princeton Univ.), Dave Miller (MIT), Charles Kyriacou (JPL), Ross Jones (JPL), Glen Kissel (JPL), Stephen Johnson (Martin Marietta)

Parallel sessions were held in each of the six key applications areas, and were moderated by the associated panel chairs. These sessions consisted of a mixture of presentations and open discussions. During the final morning sessions, which were restricted to panel members and designated guests, the panels reviewed the information presented at the workshop, and generated a set of recommendations to NASA on key technology developments in their respective areas.

This Proceedings contains the manuscripts provided by plenary and parallel session presenters, and summary reports generated from this material and from information presented during the panel discussions. Where manuscripts were not provided, extended abstracts, if available, have been included, The order of the papers follows the original workshop agenda. “l’he full workshop agenda is provided in the Appendix.

WORKSHOP PROCEEDINGS: MICROTECHNOLOGIES AND APPLICATIONS TO SPACE SYSTEMS

Workshop Summary Report

Study Coordinator and Report Editor: B. A. Wilson, JPL
Workshop Chairs: F. Y. Hadaegh, W.J. Kaiser and B. A. Wilson, JPL

Microtechnologies offer the potential of enabling or enhancing NASA missions in a variety of ways. Following in the footsteps of the microelectronics revolution, the emerging micro-electro-mechanical systems (MEMS) technology, which offers the integration of recent advances in micromachining and nanofabrication techniques with microelectronics in a mass-producible format, is viewed as the next step in device and instrument miniaturization. In the course of identifying the major areas of impact for future space missions, the following three categories emerged:

- **Miniaturization of components and systems, where the primary benefit is a reduction in size, mass and/or power. (Example: Microspacecraft.)**
- **New capabilities and enhanced performance,** where the most significant **impact is in performance, regardless of system size. (Example: Optical domain image processing.)**
- **Distributed (multi-node) systems and missions, a new system paradigm in which the functionality is enabled through a multiplicity of elements. (Examples: Distributed networks of sensors for mapping, constellations of microspacecraft, or distributed health management sensor systems.)**

The first category is the most obvious, and, not surprisingly, encompasses many of the important applications identified in this report. Nevertheless, there are also numerous examples of significant impact in the other two categories, and because they are more likely to be overlooked in a cursory survey, represent some of the most stimulating contributions of this study.

MINIATURIZATION OF COMPONENTS AND SYSTEMS

It is generally recognized that future large flagship missions will be fewer and farther between, and that we have entered an era in which smaller, lower budget missions will dominate NASA's space exploration suite. Consequently, there is a critical focus on making everything smaller, lower mass and lower power, preferably with little or no sacrifice in capability or performance. The near-term targets are for Pegasus-launched microspacecraft, for which the total mass allocation, all subsystems and instruments combined, is 10 - 400 kg. Instruments for microspacecraft missions must be concomitantly small, typically under 1 kg. The feasibility of small (< 20 kg) and miniature (< 2 kg) planetary rovers is also being considered.

The Microspacecraft panel reviewed requirements for and obstacles to achieving a 10-400 kg, first-generation microspacecraft, and no *fundamental* engineering or physics limitations were identified, Much of the required technology has already been developed, primarily within the DoD community. Key technology developments yet required include micro radioisotope thermoelectric power generators, electric propulsion, Ka–band communication systems, and embedded physical sensors. Space and mass limitations on a microspacecraft may preclude conventional modular approaches, calling for additional systems integration issues to be addressed. Other technologies such as high-density batteries, data compression techniques, mono-, bi– and solid propellant

Note: This section is page 349 - 360 in JPL Publ. 93-8.

engines and various mechanical, optoelectronic and communication s ysterns, require further modification to meet specific NASA requirements.

A number of overall recommendations were generated concerning the development and implementation of a first-generation microspacecraft. Ranked in order of priorit y, these are:

- Establish a program to flight demonstrate microspacecraft.
  - Vigorously pursue the transfer, qualification and insertion of DoD-developed technologies to NASA missions, systems and subsystems.
  - In cooperation with NASA Codes SL, SS, SZ, SE and QE, support system/mission studies of the microspacecraft concept with the goal of more effectively presenting applications, requirements, and pros and cons of microspacecraft.
  - Support the development of microspacecraft technologies that are either unique to NASA or have not been adequately supported by DoD.
- Support the micro–electro-mechanical systems R&D community with small programs and encourage investigation into NASA applications.
- Convene a Microspacecraft Working Group to increase communication between users and technologists. This working group should consist of representatives from NASA user centers, NASA technology centers, Codes R, S and Q, and the DoD contractor community.

The Guidance and Control (G&C) Panel concluded that the development of micro G&C technologies will have a revolutionary impact on future generations of NASA spacecraft and missions. Micro G&C architectures can be achieved through the integration of micromachined devices, on-chip VLSI circuitry and guidance and control functions. The core building blocks include a six-degree-of-freedom micro inertial measurement unit (IMU), actively controlled deformable mirrors, distributed microsensor systems, embedded health monitoring, and light-powered, fault-tolerant processing networks. The overall recommendations in the area of G&C encompass three phases from the planning stages to the flight experiments:

- Expedite critical analysis of microtechnology viability for G&C:
  - Examine emerging state-of-the-art microdevice technologies across various disciplines and agencies for leveraging into G&C implementations, including medical, automotive, biological, aviation and consumer product advances.
  - Conduct studies on micro G&C conceptual development, applications, and benefits, taking into account the multidisciplinary technologies involved.
- Develop and fabricate components& systems:
  - Pursue and succor promising concepts and devices, e.g. electrostatic, electromagnetic, etc.
  - Build and test prototype integrated systems.
- Validate system performance:
  - Subject promising subsystems to realistic environments and operating conditions.
  - Conduct flight experiments for validation, e.g. “get-away specials,” “piggy-back,” etc.

Miniaturization of planetary rovers will enable a wide range of future planetary exploration missions. Rovers can be considered planetary surface “spacecraft”, and much of the discussion in the spacecraft section applies equally to rovers. There are also some additional requirements, primarily in the areas of motility, including path planning and navigation, and articulation of components. Enhanced autonomy is also desirable, which requires additional microsensors and on-board processing capabilities.

The implementation of microtechnologies in sensors and science instruments is already underway, and represents a rapidly evolving area of development with the promise of additional revolutionary advances in the future. The primary impact on science instrument size is expected to result from the development of micromachined transducers, micromechanical structures, and chip-level photonics coupled with fiber-optics. The integration of electronics, photonics, and micromechanical functionalities into "instruments-on-a-chip" will provide the ultimate size advantage. The near-term advantages will most likely occur through the insertion of micromachined sensors and actuators, on-focal-plane electronics, discrete photonic components, and nanofabricated optical elements. Overall, the Science Instruments Panel of the workshop found reason for excitement in the potential of emerging microtechnologies to significantly reduce the size and power of future science instruments. Just as in the microelectronics revolution of the previous 20 years, during the next 20 years we may witness vast reductions in the cost of mass-produced items, in this case based on micromechanical and integrated MEMS technologies. This is particularly encouraging as we enter a future in which we anticipate significantly smaller missions with concomitantly reduced cost ceilings. Consequently, this panel strongly urged NASA to focus attention on the development of these technologies to permit their insertion into space missions as rapidly as possible.

NEW CAPABILITIES AND ENHANCED PERFORMANCE

In many cases, the insertion of microtechnologies and/or miniaturized systems can actually *improve* system performance or even enable new science returns. In the case of microspacecraft, for example, the smaller mass and potentially increased robustness against higher accelerations, can be translated into increased maneuverability y. This can mean more direct trajectories and shorter trips, which, in turn, reduces restrictions on the viability of instruments suffering from limited component lifetimes. It also increases the possibilities for multi-destination missions. Enhanced performance may also be possible for individual spacecraft subsystems such as communications, data management, G&C, and embedded sensor systems, which could be used to advantage in micro and conventionally sized spacecraft alike. Micromechanical structures are particularly promising for improving the capabilities of inertial sensors and robotic manipulators.

Increased sensitivity, frequency response, dynamic range, resolution and robustness can often be achieved in science sensors through the use of microtechnologies. One of the key components is the micromachined transducer. A prime example is the tunnel sensor, an ultra-sensitive new transducer based on electron tunneling between a micromachined tip positioned a few Å above an underlying surface, all fabricated on a single silicon wafer. Reconfigured as a transducer, tunneling structures can reveal changes in the tip-surface separation with accuracies of 0.1 Å or better, representing an increase in sensitivity of many orders of magnitude over conventional transducers. Nanofabrication and lithographically defined transducer structures offer large enhancements in sensitivity over conventional approaches. Microchemical sensors offer the possibility of in-situ chemical sensing. A second technology area of critical importance to future science instruments is the application of micro and nanofabrication techniques to optics and optical systems. Microactuators will play a key role in advanced optical systems. Micromachining techniques offer significant enhancements in X-ray imaging resolution, and new opportunities in electrostatic imaging and vacuum electronics for chip-level particle detection and analysis. Nanolithography of optical surface structure is another key element. Lithography on the nm scale is also required for the fabrication of high-frequency receiver components, phased-array antennas and chip-level photonic devices.

DISTRIBUTED SYSTEMS

Perhaps the most stimulating and provocative opportunities for new mission capabilities and science return emerging from the workshop fall into this category. We are at the threshold of the MEMS revolution, anticipated to have as far-reaching an impact on the miniaturization and cost reduction of components as the microelectronics revolution we have already experienced. With the availability of mass-produced, miniature instrumentation comes the opportunity to rethink our fundamental measurement paradigms. It is now possible to expand our horizons from a single instrument perspective to one involving multi-node or distributed systems. As the largest departure from conventional approaches, advances in this area are the hardest to predict, but maybe the most far-reaching.

Given the possibility of launching suites of microspacecraft, it is appropriate to consider the benefits of multi-spacecraft missions. Advantages for Eos–type missions include simultaneous multi-swath mapping, Placing two or more satellites at appropriately phased intervals in the same orbit enables direct active measurements through the atmospheric layers of interest. Multiple spacecraft can also be used as nodes along an extended interferometric baseline, or as points of a gigantic linear unfilled aperture array. Distributed sensor systems offer performance advantages in health management for conventional and microspacecraft. The greatest impact is expected for fuel and propulsion systems, G&C systems and life-support systems, which will require the development and insertion of physical, chemical and biological sensors. Propulsion and fuel systems would benefit from suites of temperature, pressure and specific chemical sensors for leak detection.

One of the most exciting ideas that emerged from the workshop is the concept of utilizing distributed sensor systems for extending the scope of possible science measurements. Similar to the breakthrough in science return offered by focal-plane arrays versus discrete detector elements, distributed arrays of sensors can provide extended sets of information that lead to new levels of understanding of the underlying phenomena. Multi-node sensor systems enable both imaging/mapping activities, as well as the acquisition of time-phased/dynamic information unavailable from a single-sensor measurement mode. For example, while a single seismometer can only indicate the local ground acceleration, multiple sensors distributed across the planetary surface can lead to a detailed understanding of global seismic activity and the nature and structure of the planetary interior. Examples of science instruments where the advantages of distributed arrays are on the horizon include seismometer arrays, free-flying magnetometers, planetary surface constituent analysis, and fiber-optic-linked, free-space interferometers. Complex science instruments may also benefit from embedded arrays of microsensors to monitor their system functionality.

MICROTECHNOLOGY DEVELOPMENT RECOMMENDATIONS

An integrated assessment of the panels suggests that the predominant near-term impact of microtechnologies on NASA space missions is most likely to occur in two areas: (i) the implementation of miniature systems utilizing existing technology; and (ii) the insertion of micromachined sensors and actuators. The miniaturization of spacecraft, planetary rovers and science instruments can proceed rapidly with the incorporation of miniature technologies that have already been developed at the component level, but not yet integrated into appropriately designed miniature systems. Compact packaging technologies will also assist in this process. New miniaturization opportunities are offered by emerging micromachined sensors and actuators, selected chemical sensors, discrete photonic devices, and lithographically defined micro–optics technologies

Further miniaturization and performance enhancement of spacecraft, planetary rovers and science instruments will be possible as the on-chip integration of micromechanical and electronic components becomes feasible. Coupled with the development of appropriate processing networks, this should enable the first distributed sensor systems for health management applications. Other important mid-term impact areas include the incorporation of binary and adaptive optics and the development of space-qualifiable high-speed electronic systems for Ka–band communications and adaptive processing networks. More fundamental advances are likely to provide additional system advantages further downstream. To ensure that areas relevant to space applications emerge in a timely manner, it is recommended that NASA consider base-program support in selected areas of long-term pay-off. These include micromachining and nanofabrication techniques of greater sophistication and in new materials including binary optics, chemical and biological microsensor development, vacuum electronics components, integrated photonic technologies, and fundamental advances in concurrent processing architectures.

CONCLUSIONS

As the first forum spanning the emerging microtechnologies and bringing together the technology and space systems experts across the country, the workshop was enthusiastically supported by all parts of the community. Over 225 people participated in this workshop, drawn from universities, industry, NASA centers, and other government laboratories and agencies. The workshop was chaired by Fred Hadaegh, Bill Kaiser and Barbara Wilson, with presentations over viewing emerging microtechnology developments coordinated by Frank Grunthaner. Following the workshop, a set of recommendations to NASA in support of the key technology development areas was generated as an interim internal report, which was subsequently incorporated into the NASA technology planning process.

Microtechnologies
and
Application to Space Systems Workshop

APPENDIX

MICROTECHNOLOGIES AND APPLICATIONS TO SPACE SYSTEMS WORKSHOP

AGENDA

DAY 1: May 27.1 992

WELCOME - Barbara Wilson, Session Chair

8:00 am *Workshop Welcome*	Terry Cole, JPL
8:15 am *Workshop Overview*	Wayne Hudson, NASA Code RS

FUTURE VISIONS - Gordon Johnston, Session Chair

8:30 am *Future Trends in Small Missions and Need for Microtechnology*	Charles Elachi, JPL
8:50 am *The NSF Microtechnology Program, or Robots on the Head of a Pin*	George Hazelrigg, NSF
9:20 am Silicon *Micro-Instrumentation*	Kurt Petersen, Lucas NovaSensor

NASA MISSION & SCIENCE GOALS - Wayne Hudson, Session Chair

10:10 am *The Solar System Exploration Program: Goals, Strategy, and Plans*	Corinne Buoni, SAIC
10:30 am Science Goals & Constraints *of MESUR*	Arthur Lane, JPL
10:50 am *The Fast Flyby Pluto Mission: Completing the Reconnaissance of the Solar System*	Paul Henry, JPL
11:10 am *Space Physics Mission Needs*	Jim Randolph, NASA Code SS
11:30 am *Mission & Science Goals of Lunar Outpost Missions*	Jeffrey Plescia, JPL

MICROTECHNOLOGY PROGRAM OVERVIEWS PART I - Frank Grunthaner, Session Chair

1:00 pm *Micro Electro Mechanical Systems (MEMS) and Their Impact on Future Robotic Systems*	Stephen Jacobsen, Univ. of Utah
1:20 pm *SDI Development of Miniaturized Components*	Mick Blackledge, SDI/TN
1:50 pm *DoD Advanced Space Technology Program Challenge*	Al Wheatley, DARPA
2:10 pm *Code R Microtechnologies*	Dave Lavery, NASA Code RS
2:30 pm *Micromechanics Program at Sandia: Micromechanical Sensors, Actuators and Devices*	Ned Godshall, Sandia
2:50 pm *Micromanufacturing: Recent Developments in this Country and Abroad*	Robert Barrington, Louisiana Tech Univ.
3:10 pm *Microsensors and Microinstruments: New Measurement Principles and New Applications*	William J. Kaiser, JPL

MICROTECHNOLOGY PROGRAM OVERVIEWS PART II - William Kaiser, Session Chair

5:00 pm *Micro-Sensors, -Actuators, -Systems: Accomplishments & Prospects*	Richard White, UC Berkeley
5:20 pm *National Nanofabrication Facility and Nanoelectromechanics*	Noel MacDonald, Cornell Univ.
5:40 pm *Microactuator Production via High Aspect Ratio, Edge Acuity Metal Fabrication Technology*	Henry Guckel, Univ. of Wisconsin-Madison
6:00 pm *Overview of Microoptics: Past, Present and Future*	Wilfrid Veldkamp, Lincoln Laboratory, MIT
6:20 pm *Microsensors, Smart Sensors, Sensor Arrays, and the Artificial Nose*	Joseph Netter, Transducer Research Inc.

DAY 2: May 28.1992

AI'PLACATIONS OVERVIEWS PART I - John DiBattista, Session Chair

8:00 am	*Micromechanical Actuators*	William Trimmer, Princeton Univ. & Belle Mead Research
8:30 am	*In Situ Meteorological Sensors for Earth and Mars Applications*	James Tillman, Univ. of Washington
8:50 am	*Silicon Flexural Microelectromechan ical Devices*	Kaigham Gabriel, NRL
9:10 am	*Micromachining the Future*	Marc Madou, Teknekron
9:40 am	*Learning from Biology - Motor Systems at all Scales*	M.G. Littman, Princeton Univ.

APPLICATIONS OVERVIEWS PART II - Fred Hadaegh, Session Chair

0:20 am	*Micro-Software for Micro-Robots*	David Miller, MIT
0:40 am	*Spacecraft Telecommunications Technology for Microspacecraft*	Charles Kyriacou
1:00 am	*Microspacecraft: A Concept*	Ross Jones, JPL
1:20 am	*Micro-Guidance and Control Technology Overview*	Glen Kissel, JPL
1:40 am	*Health Management Issues for Space Systems*	Stephen Johnson, Martin Marietta Astronautics

PARALLEL SESSION ON SCIENCE INSTRUMENTS

SESSION AND PANEL CHAIRS: Benton Clark, Gregg Vane & Louis Watts

1:00 pm	*Trends in X-Ray Fluorescence Instruments*	Benton Clark, Martin Marietta
1:20 pm	*Miniaturization in X-Ray and Gamma-Ray Spectroscopy*	Jan Iwanczyk, Xsirius, Inc.
1:40 pm	*Backscatter Mossbauer Spectrometer (BaMS) for Extraterrestrial Applications*	David Agresti, Univ. of Alabama
2:00 pm	*A Sub-cm Micromachined Electron Microscope*	Alan Feinerman, Univ. of Illinois at Chicago
2:20 pm	*Differential Scanning Calorimetry for Planetary Surface Exploration*	Douglas Ming, JSC
2:40 pm	*Micro-Sensors for in-situ Meteorological Measurements*	David Crisp, JPL
3:00 pm	*A Broad-Band Microseismomete r for Planetary Applications*	Bruce Banerdt, JPL
3:40 pm	*The Miniature X-Ray Telescope ALEXIS*	Bill Priedhorsky, Los Alamos
4:00 pm	*Imaging Spectrometry for the Earth and Other Solar System Bodies*	Gregg Vane, JPL
4:20 pm	*Smart Focal-Plane Technology for Micro Instruments and Micro Rovers*	Eric Fossum, JPL
4:40 pm	*Evolution of Miniature Detectors and Focal Plane Arrays for Infrared Sensors*	Louis Watts, SAIC
5:00 pm	*Photonics Devices for Microinstruments*	Robert Lang, Spectra Diode

PARALLEL SESSION ON MICROSPACECRAFT

SESSION AND PANEL CHAIRS: Denis Connolly, Ross Jones

1:00 pm	*Asteroid Investigation with Microspacecraft (AIM)*	Ross Jones & Christopher Salvo, JPL
1:20 pm	*Fundamental Limits on Earth Remote Sensing from Small Spacecraft*	David Rider, JPL
1:40 pm	*Development of MMIC Technology for SATCOM Applications*	John Berenz, TRW
2:00 pm	*Spacecraft Telecommunications Technology for Microspacecraft Applications*	Charles Kyriacou, JPL
2:20 pm	*Power Subsystem State-of-the-Art Assessment and Miniaturization Technology Needs*	Robert Detwiler, JPL
2:40 pm	*The Application of Micro Technology to Spacecraft On-Board Computing*	Leon Alkalaj, JPL
3:20 pm	*Command & Data Subsystem Technology*	Richard Grammier, JPL

3:40 pm	*Electronic Packaging for Microspacecraft Applications*	David Wasler, JPL
4:00 pm	*Microspacecraft Attitude Control*	George Sevaston, JPL
4:20 pm	*Miniaturized Propulsion Systems*	Dale Hook, TRW
4:40 pm	*Lightweight Structures and Mechanisms for Microsatellites*	Robert Wendt, Martin Marietta
5:00 pm	*SDI Flight Tests of Integrated Microsystems*	Rich Matlock, SDI/TN

PARALLEL SESSION ON SPACE STATION, SHUTTLE & PROPULSION
SESSION AND PANEL CHAIRS: W.T. Powers, Gerald Voecks

1:00 pm -6:00 pm Roundtable Discussions and presentations

PARALLEL SESSION ON MICROROVERS
SESSION AND PANEL CHAIRS: Kaigham Gabriel and Subramani Venkataraman

1:00 pm	*Role of Microrovers in Planetary Exploration*	Corinne Buoni, SAIC
1:25 pm	*Robotic Vehicles for Planetary Exploration*	Brian Wilcox, JPL
1:50 pm	*Application of Behavior Control Technology to Planetary Rovers*	Rajiv Desai, JPL
2:15 pm	*Difficulties Inherent in Miniaturizing Current Rover Technologies for Use as Planetary Explorers*	Gerald Roston, CMU
2:40 pm	*Micromachining Technologies for Automotive Applications*	William Tang, Ford Motor
3:05 pm	*Microtechnology on Minirovers*	Donald Bickler, JPL
3:50 pm	*Silicon Flexural Microelectromechanical Devices*	Kaigham Gabriel, NRL
4:15 pm	*Micromechanical Actuators*	William Trimmer, Princeton Univ. & Belle Mead Research
4:40 pm	*Toward Mini-Newton Electro- and Magneto-Static Microactuators*	Long-Shen Fan, IBM Almaden
5:05 pm	*Micro Structures and Micro Actuators for Implementing Sub-Millimeter Robots*	Ronald Fearing, UC Berkeley
5:30 pm	*Coordinated Control of Legged Locomotion via Nonlinear Oscillators*	P. Krishnaprasad, Univ. of Maryland

PARALLEL SESSION ON MICROTECHNOLOGIES OF THE FUTURE
SESSION AND PANEL CHAIRS: Frank Grunthaner, John Hines and Brent Mott

1:00 pm -6:00 pm Roundtable Discussions and presentations

PARALLEL SESSION ON GUIDANCE & CONTROL
SESSION AND PANEL CHAIRS: John DiBattista, Fred Hadaegh and Claude Keckler

1:00 pm	*Control of Micro-Machined Deformable Mirrors*	P.K.C. Wang, UCLA
1:25 pm	*Emerging Technologies in Microguidance and Control*	Marc Weinberg, C.S. Draper Laboratory
1:50 pm	*An Electrostatically Suspended, Micro-Mechanical Rate Gyroscope*	Timothy Hawkey, SatCon Technology Corp.
2:15 pm	*GEC Ferranti Piezo Vibratory Gyroscope*	John Nuttall, GEC Ferranti
2:55 pm	*The Application of Micromachined Sensors to Manned Space* Systems	Gary Havey, Honeywell Systems & Research
3:20 pm	*Micro Guidance and Control Synthesis: New Components, Architectures and Capabilities*	Edward Mettler, JPL
3:45 pm	*Microoptomechanical Devices &* Systems *using Epitaxial Lift-Off*	Mark Allen, Georgia Inst. of Technology
4:10 pm	*Miniature Wide Field-of-View Star Trackers for Spacecraft Attitude Sensing & Navigation*	William McCarty, OCA Applied Optics, Inc.
4:35 pm	*Novel Position Sensor Technologies for Micro Accelerometers*	Thomas Van Zandt, JPL

WORKSHOP PANELS

PANEL ON SCIENCE INSTRUMENTS

PANEL CHAIRS: Benton Clark, Gregg Vane& Louis Watts

PANEL MEMBERS

Arden Albee, Caltech
James Bradley, JPL
Benton Clark, Martin Marietta
Eric Fossum, JPL
Raymond Goldstein, JPL
Gordon Johnston, NASA Code RSS
William Kaiser, JPL
James Tillman, Univ. of WA
Gregg Vane, JPL
Wilfrid Veldkamp, MIT Lincoln Labs
Louis Watts, SAIC

PANEL ON MICROSPACECRAFT

PANEL CHAIRS: Denis Connolly, Ross Jones

PANEL MEMBERS

Leon Alkalaj, JPL
John Berenz, TRW
Corinne Buoni, SAIC
Richard Cheng, Hughes
Denis Connolly, LeRC
Robert Detwiler, JPL
Terry Gamber, Martin Marietta
Rick Grammier, JPL
Dale Hook, TRW
Ross Jones, JPL
Charles Kyriacou, JPL
Robed Lafferty, Motorola
Rich Matlock, SDI/TN
John McIver, Boeing
Rich Reinert, Ball Aerospace
George Sevaston, JPL
Dave Stevens, JPL
David Wasler, JPL
Robert Wendt, Martin Marietta

PANEL ON SPACE STATION, SHUTTLE& PROPULSION

PANEL CHAIRS: W.T. Powers, Gerald Voecks

PANEL MEMBERS

David Blackburn, NIST
Rod Bogue, Ball Aerospace
Thurman I Henderson, U. of Cincinnati
Richard Higgins, GA Tech Res. Inst.
Stephen Johnson, Martin Marietta
Kevin Kellenberger, KSC
C.C. Liu, Case Western Reserve
Wally Parce, Molecular Devices
Marc Porter, Iowa State Univ.
Greg Schunk, MSFC
John Simpson, Rocketdyne
Raoul Tawel, JPL
W.T. Powers, MSFC
Dave Venezky, NRL
Gerald Voecks, JPL

PANEL ON MICROROVERS

PANEL CHAIRS: Kaigham Gabriel and Subramani Venkataraman

PANEL MEMBERS

Rajiv Desai, JPL
Long-Shen Fan, IBM, Almaden
Kaigham Gabriel, NRL
Dave Lavery, NASA Code RS
Michael Sims, ARC
Bill Tang, Ford Scientific Res. Lab.
Subramani Venkataraman, JPL
Brian Wilcox, JPL

PANEL ON MICROTECHNOLOGIES OF THE FUTURE

PANEL CHAIRS: Frank Grunthaner, John Hines and Brent Mott

PANEL MEMBERS

Robert Hughes, Sandia
Stephen Jacobsen, Univ. of Utah
Seun Kahng, LaRC
Thomas Kenny, JPL
Ned Godshall, Sandia
Frank Grunthaner, JPL
John Hines, ARC
Mark Madou, Teknekron
M. Mehregany, Case Western Res.
Harvey Moseley, GSFC
Brent Mott, GSFC
Kurt Petersen, Lucas NovaSensor
Stephen Senturia, MIT
Joseph Stetter, Transducer Research
Yu-Chong Tai, Caltech
Joseph Warner, LeRC
Robert Warrington, LSU
Richard White, UC Berkeley

PANEL ON GUIDANCE& CONTROL

PANEL CHAIRS: John DiBattista, Fred Hadaegh and Claude Keckler

PANEL MEMBERS

Randy Bartman, JPL
Frank Bauer, GSFC
John DiBattista, NASA Code RSR
Nelson Groom, LaRC
Fred Hadaegh, JPL
Gary Havey, JSC
Dean Jacot, Boeing
Claude Keckler, LaRC
Glen Kissel, JPL
Henry Lum, Jr., ARC
John Shackelford, General Dynamics
Henry Waites, MSFC