Telescience Testbedding: An Implementation Approach

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Telescience is the term used to describe a concept being developed by NASA's Office of Space Science and Applications (OSSA) under the Science and Applications Information System (SAIS) Program. This concept focuses on the development of an ability for all OSSA users to be remotely interactive with all provided information system services for the Space Station era. This concept includes access to services provided by both flight and ground components of the system and emphasizes the accommodation of users from their home institutions.

Key to the development of the Telescience capability is an implementation approach called rapid-prototype testbedding. This testbedding is used to validate the concept and test the applicability of emerging technologies and operational methodologies. Testbedding will be used to first determine the feasibility of an idea and then the applicability to real science usage. Once a concept is deemed viable, it will be integrated into the operational system for real time support. It is believed that this approach will greatly decrease the expense of implementing the eventual system and will enhance the resultant capabilities of the delivered system.

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1. The Telescience Concept

Space Station and its associated laboratories, coupled with the availability of new computing and communications technologies, have the potential of significantly enhancing scientific research. To assure that this potential is met, scientists and managers associated with the Space Station project must gain significant experience with the use of these technologies for scientific research, and this experience must be fed into the development process for Space Station. The SESAC Task Force on the Scientific Uses of Space Station (TFSUSS) has used the word *telescience* to refer to the concept in which interactive high-performance telecommunication links exist among the space-based laboratories and facilities, the on-orbit crew, and geographically dispersed ground-based investigator groups. Instead of being a remote outpost, Space Station is then an accessible and integral part of the research infrastructure.

The distributed interaction is meant to include ALL members of a user team; in space and on the ground, and may involve either manned or automated operations. For convenience, Telescience has been broadly divided into three components:

1. Teledesign - the ability to send drawings, documents and specifications, to perform interactive design with remote facilities, and to conduct interface and other tests of instruments by remote computer access.
2. Teleoperations - the ability to conduct remote operations by making rapid adjustments to instrumental parameters and experiment procedures in order to obtain optimum performance.
3. Teleanalysis - the ability to access and merge data from distant sources and to perform analyses and studies on computers that may be located at other institutions.

The general principles outlined above are common to all disciplines, but the working parameters vary from case to case. Different disciplines require different time scales. For example, some astronomers would like the ability to fine-tune telescope pointing and filtering on a time scale of seconds, whereas Earth Observations projects are likely to be satisfied with adjustments made once per orbit. Some projects expect to work in a pre-planned mode most of the time, but want the ability to react rapidly to a variety of unanticipated events that cannot be predicted and incorporated into pre-planned operations. Examples are solar flares, volcanic eruptions and supernova explosions. In all these cases, projects need to recognize such events and reconfigure their instrument operations with great rapidity.

It is, of course, inherent in this concept that computer networking must be available for scientist-to-scientist communications as well as for accessing the remote distributed services required for scientific investigation, including databases and computing resources. It is also clear that Telescience concepts should be built into the design of both space and ground systems at the outset. Furthermore, commonality of interfaces and protocols is of vital concern for the conduct of science by a varied international community and the emerging needs for interdisciplinary research involving the joint operation of disparate instruments and the merging of their varied data sets.

To make the telescience concept a reality, there are a large number of issues that need to be investigated and resolved. Examples of these issues are the following:

Impact of Distribution of Users

In the Space Station era, scientific investigations will involve teams of scientists, distributed across the nation and internationally, collaborating on scientific experiments that last years. What is the impact of this distribution on questions such as data management, data analysis, command checking (and operations in general), and scheduling of resources?

Telescience Implications on Modes of Operation

Telescience means that scientists will be able to carry out many if not all phases of their experiments remotely from the experimental hardware and other computing and data analysis resources. What is the implication on the way scientists interact with the experiments? What in turn is the implication on the design of the experimental hardware and software so as to permit teleoperation and teleanalysis? What is the impact on the allocation and scheduling of resources when there is multiple demand as well as the need to take advantage of serendipitous discoveries?

Command Management Methods

The ability to modify and carry out experiments in near real-time means that the methods for command management for those experiments need to be reevaluated. This in turn will have impact on the location and types of processing associated with such command management.

Required Access to NASA and non-NASA Data Bases

Both teledesign and teleanalysis will require some form of access to engineering data bases as well as data archives from previous experiments. How should that access be provided for? Should it be done with standard interfaces? Is there a way of standardizing the form of the data format to allow growth and evolution?

Data Handling Concepts

Experiments carried out in the Space Station environment are likely to last for many years. Some of these experiments will be gathering data that will contain critical events that are useful for years following. How should these data be archived and what data management techniques should be used to enable scientists in the outyears to gain access to the data expeditiously?

Coordination of Data Gathering

Not only will users be distributed in the future, but many experiments, particularly earth observation experiments, will take advantage of multiple resources operating simultaneously (campaign mode.) How can these various resources be coordinated in their data gathering activity? How can the data that results be analyzed in an effective manner?

Impact of Multi-disciplinary Activities

Space Station and similar resources will be used by multiple disciplines carrying out multiple experiments simultaneously. How can the use of the resources be planned and scheduled? How can the dynamics of scientific experimentation (opportunistic experiments based on real-time observation) be accommodated?

Interaction of Autonomous Behavior and Teleoperation

Effective experimentation will require some level of intelligence (autonomy) in the remote experimental resource. Yet advances in telecommunications have allowed scientists to have near-real-time interactions with their experimental apparatus. What effect will these two forms of interaction (autonomous vs. teleoperations) have with each other?

Requirements for Access Control, Privacy, and Authentication

The scientific experimental environment in the Space Station era will have many components interacting with many users. This raises several issues concerning privacy, access control, and authentication. How should access control for both data and experimental resources be provided? How should a scientists' proprietary rights to data generated from their experiments be protected? How should commands to experimental equipment be authenticated, for example to avoid interference between experiments? What are the basic requirements for these security-related functions?

Network Performance Requirements

Telescience is based on having capable computer communication networking capability. This is required to support all phases from teledesign through teleoperations to teleanalysis. What are the performance requirements of such a network? This includes both obvious parameters such as delay, bandwidth, and error rate as well as more subtle requirements as the need for high duty cycle connections, for example for down-linking of SAR data, versus more bursty requirements for interactive control. What are the potential bottlenecks in the system, and how can they be alleviated?

2. A Testbedding Approach

Investigation and resolution of these issues requires the cooperation of technologists, system developers, and users to determine the overall design concepts, the technologies required, and the role that such technologies can play in support of scientific research. The traditional approach to requirements definition is to ask a representative group of users to develop those requirements prior to system design and development. This approach has severe limitations. It does not recognize the fact that users lack sufficient experience with new technology to specify engineering requirements and that requirements are dynamic and evolving throughout all phases of a project.

The user-oriented rapid-prototyping testbed approach described here represents what we believe to be the best method for assuring that the developed and deployed systems of the future satisfy the true user requirements. It allows for investigation and validation of new systems concepts as well as methods for the scientists to exploit the system in carrying out their scientific research. It permits new state-of-the-art technologies to be evaluated with respect to their role in the overall systems architecture and their ability to support user needs. Finally, it results in an educated user community capable of intelligently conducting ongoing review of the systems requirements, design, and specifications

The testbedding approach uses a distributed environment for the rapid prototyping and evaluation of new concepts and techniques. Such an environment is separate from any testbed used to evaluate the actual hardware and software of the system under development (e.g. Space Station and the SSIS). Rather, the environment would provide a mechanism for rapid prototyping of new ideas and technologies, so that users (scientists) can carry out their research using these prototypes. This would allow early and rapid evaluation of the role that such technologies can play in support of scientific research. This in turn allows the users and developers to more realistically assess requirements, specifications, and design of the system while they are still in paper design stage, and before major investments in hardware and software are made.

The testbedding environment consists of a number of testing and prototyping capabilities all interlinked through a common communication network. This will allow rapid prototyping of advanced concepts and technologies and evaluation of those concepts in supporting research in space. The facility is specifically not a single physical facility. Rather it is an infrastructure for supporting experiments throughout the country and community.

Physically, the environment should provide high-bandwidth networking (at least 1 Mbps) interlinking scientists at a selected set of universities, all NASA laboratories, certain industrial research laboratories, and key contractor facilities. The software should incorporate:

- standardized protocols
- user-friendly interfaces
- a simplified uniform command language
- transparent gatewaying to a variety of LANs
- file transfer and interactive computing channels
- "intelligent" help files

Using this environment, groups of scientists in a particular discipline combined with computer science researchers (to provide state of the art technology) combine forces to carry out scientific experiments. The experiments should be carefully planned to evaluate the role that new technologies can play in carrying out scientific research. In particular, experiments should be carried out to validate concepts such as telescience and address critical issues such as the ones described above. These experiments will range from investigations of required communications support through computer processing requirements and the need for knowledge-based systems to support capabilities such as intelligent information retrieval and data analysis. Experiments should also be designed to support trade-off analyses; e.g. Would a particular scientific experiment benefit more by increased communications or increased local processing on the Space Station? Another example would be examining the trade-off between reliability and bandwidth in communications. The distributed nature of the testbed will allow scientists and technologists at various sites to join forces in carrying out these experiments without having to be physically co-located.

Note that these experiments are not designed to evaluate particular hardware or software. Rather, they use early prototypes of new technological functionality to evaluate advanced concepts, new methods of operation, and effectiveness of the technological support of those concepts. This allows a better definition of requirements and specifications.

3. A Prototype Testbed Program

The NASA's Office of Space Science and Applications (OSSA) has initiated a pilot program to validate the user-oriented rapid-prototyping testbed approach. Fifteen universities, under subcontract to the Universities Space Research Association (USRA), are conducting a variety of scientific experiments emulative of the scientific research of the Space Station era and aimed at resolving critical issues in Space Station Information Systems design. The goal is to allow scientists to interact with potential space station technologies in a manner that will allow resolution of design and specification questions without having to wait until space station hardware is available. The following is a short synopsis of the testbed experiments currently ongoing as part of the pilot program.

University of Arizona is conducting two experiments. The first involves teleoperation of a forerunner of the Astrometric Telescope Facility, which will be an attached payload for Space Station. The second is developing systems and software for remote fluid handling in support of microgravity and life sciences. Arizona is also participating in the SIRTF project described below.

University of California, Santa Barbara is exploring teleanalysis of large dynamic data sets for earth sciences. This investigation includes the test and evaluation of data interchange standards and knowledge based techniques for assisting remote access.

University of Colorado is investigating the cooperative use of data from the Solar Mesosphere Explorer for coordinated measurements, remote access and control. It is also applying a user-workstation-oriented control concept to a number of telescience experiments collaboratively with other program participants.

Purdue University is evaluating teleanalysis concepts using the Purdue Field Spectral Database accessed by a variety of small computers. It is also investigating methods for conducting campaign style experiments and computer data security issues.

Rensselaer Polytechnic Institute is establishing a testbed to experimentally determine the level of communications capability required to successfully perform remote controlled materials processing experiments of the Space Station era. Three different types of experiments will be tried with the cooperation of the Microgravity Materials Science Laboratory at Lewis Research Center.

University of Michigan is experimenting with teleoperations of a Fabry-Perot Spectrometer combining human with autonomous control, forward simulation techniques to support telerobotics, and the effects of varying time delays in the control loop.

University of Wisconsin is providing a bridge from NSFnet to McIdas, allowing any TTPP participant with access to NSFnet to acquire existing meteorological products from McIdas.

Stanford University is experimenting with a model Remote Science Operations Center linked to GSFC, JSC and MSFC using real data from Spacelab 2 to test multimedia Telescience workstations and simulate remote control, monitoring and multi-media conferencing.

MIT is conducting two experiments. The first is a Remote Life Sciences Operation using the KSC sled with multi-media tests and evaluation of real video needs and implementation options. They also are investigating the remote operation of a telescope at Wallace Observatory using a high bandwidth (T1) link and dissemination of data on campus-wide Project Athena network.

The Space Infrared Telescope Facility (SIRTF) team, consisting of Cornell University, Smithsonian Astrophysics Observatory, CalTech, University of Rochester and University of Arizona, are investigating several issues regarding telescience applied to a Space-based astronomical facility. They are evaluating distributed versus resource-centered models for development (teledesign) and remote access. The ability to interchange analysis software and perform in conference mode for design, operations and analysis will be evaluated. University of Arizona has a special interest in remote control and operations of a ground-based telescope to evaluate feasible degrees of automation, allowable time delays, necessary crew intervention, error control and feasible data compression schemes. Cornell University is investigating trade-offs between on-line local processing and processing at the user's home location as well as investigating the feasibility of establishing standard formats and analysis techniques. Smithsonian Astrophysical Observatory is using remote operation of Mt. Hopkins telescope to evaluate data transmission and dissemination options.

University of California at Berkeley is extending control and simulation systems developed for EUVE to evaluate techniques for remote instrument control over local and wide area networks. Distributed development environments in use at Berkeley are being extended to facilitate coordinated development by cooperating institutions.

University of Rhode Island is investigating a novel image compression technique with "zoom" capability to help progress from browsing to detailed analysis of selected areas using modest bandwidths from remote sites.

RIACS (Research Institute for Advanced Computer Science) is integrating various networking and local computing capabilities into a "telescience workstation", intended to provide a local computing environment for telescience.

These experiments all share the characteristic that they are attempting to apply new technologies and concepts of science operation to ongoing scientific activities. In that process, a better understanding will be gained of the future scientific modes of operation and the systems architectures, concepts, and technologies required to support such operational modes.

Associated with this University oriented aspect of the OSSA testbedding activity is a NASA Center oriented portion which is focussing on the application of emerging technologies in the institutional development of the telescience concept. This element of the testbedding program is investigating the services provided across scientific disciplines and within existing systems. Included are standards development, generalized planning and scheduling schemes, user access capabilities to heterogeneous systems, system monitor and control mechanisms, and methods for managing the overall system. It is through the collaboration between these two aspects of the program (University oriented and Center oriented) that we hope to find the desired approach for developing the very complex, distributed, multidisciplinary systems needed for the Space Station era. Combining these two elements with the third aspect of the program, international testbedding, results in the necessary ingredients for the development of a truly global system capability which can serve the needs of the entire science community.

4. Summary and Conclusions

We have described a new approach to involving users in the development process through the use of a rapid-prototyping testbed. The approach has significant advantages over prior techniques using user surveys or similar approaches to state requirements.

- It allows study of the interaction of new technologies and scientific operations in a cost-effective manner.
- It assures usability of the end system by validating the technological and operational approaches in an ongoing process.
- It provides for ongoing technology enhancement where such enhancement can be shown to improve the scientific process itself.
- It develops an educated user community capable of sharing the responsibility for system requirements and specification with the system developer.

It is thus envisioned that testbedding will enhance our systems engineering and integration ability by pointing out problems early in the development process. By testbedding difficult concepts and low probability implementations early enough in the process, we can increase our ability to use more current technology and minimize the effects of failure during the later stages.

This approach should be used at all stages of the system development. During design, it can be used to validate requirements and technical approaches. During implementation it can be used to test the applicability of individual designs. During integration it can be used to isolate problems for more concentrated tests. This approach will, therefore, have the bottom line effect of considerable increase in cost- effectiveness in the system development process.

In short, we believe that the user-oriented rapid-prototyping testbed concept is a valuable adjunct to the systems development process. The pilot program described above is designed to show its viability.

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