Mission Operations Control Applications -- A commercial mission to extend, validate, and apply the NASA MCT toolkit for ISS experiment control

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This mission focuses on the development of integrated end to end mission operations control applications for technology development research. This mission proposes to further develop and demonstrate the use of NASA Ames Mission Control Technologies (MCT) software (Open MCT Web) as an extensible tool set for potential technology development missions. The MCT toolkit and development environment software can be leveraged to accelerate development, facilitate required interface management (machine – machine, human – machine) through the use of near real time parametric state models and streamline the path to use in future missions such as Space to Space Power Beaming. MCT's extensible architecture brings object orientation to the user interface, presenting users with a graphical user interface that is both object oriented and composable. Rather than interacting with traditional applications, users interact with user objects, which they can compose on screen to function as needed, without requiring an additional application for creating compositions. Compositions can then be managed by policies, providing a mechanism to implement organizational policies in software. The product of this mission is to provide future International Space Station experiment control software development teams an improved and extended set of MCT software functionality to remotely interact with and control their experiments taking advantage of near real time parametric state models. Use of the extended MCT software will allow for more efficient, consistent and higher quality software development.

Nomenclature

I. Introduction

The Mission Operations Control Applications (MOCA) body of work is an opportunity to craft viable technology demonstrations that will establish the basis for a confluence of interest between real mission users and the technology development effort.

This effort seeks to develop new tools to address N-Dimensional interaction problems (i.e., an arbitrary number of objects interacting in an arbitrary number of ways) as a class of problems for which the generalized solution space is computationally intractable in any time frame.

This work can support a range of technology development missions on International Space Station (ISS) and subsequent flight opportunities that can make efficient and effective use of near realtime state models and the enhanced Open MCT Web Software suite[1]. Open MCT is a next-generation mission control framework being developed at NASA's Ames Research Center in Silicon Valley, in collaboration with the Jet Propulsion Laboratory. This is the latest instance of the software steming from the NASA ARC Mission Control Technologies Lab research effort[2-5]. The MCT open source software suite has been used by a range of missions including Project Morpheus and the Mars Science Laboratory Curiosity Rover. Software based on Open MCT is being used for mission planning

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and operations in the lead up to the Resource Prospector mission at NASA's Ames Research Center, and as a data visualization tool at the Jet Propulsion Laboratory.

We propose the development of space-to-space power beaming by leveraging ISS resources to create a space-to-space power beaming testbed environment on and in the vicinity of ISS. This can be mission enhancing if not mission enabling for a range of Earth facing, space operations/development, and space exploration missions.

This work supports the unbundling of multiple spacecraft systems (e.g., power, communications/data, navigation, attitude control and determination, propulsion, etc.). This can have synergistic effects which allow for:

1) reduction in spacecraft complexity, mass and/or volume,
2) reallocation of spacecraft mass and/or volume,
3) employment of Delay and Disturbance Tolerant Networking (DTN) as an operational tool,
4) alter the cadence of spacecraft mission operations,
5) reduce or eliminate solar pointing requirements, and/or
6) impart additional delta-V to a spacecraft either indirectly (power augmentation) or directly (momentum transfer).

An example of these synergistic effects would be using a combination of power & communications/data beaming and DTN to reduce the size, mass, and power requirements of an autonomous system/spacecraft. This approach would allow the use of smaller power supplies and batteries on board the spacecraft for keep alive activities and beaming capabilities when the spacecraft requires additional resources to support operations, adjusted as needed.

This effort bridges technology development, technology demonstration, and technology deployment. This work serves to reinforce the United States relevancy in the global high-tech marketplace competiveness as well as providing extraordinary opportunities for international cooperation and collaboration.

II. Mission Definition

The MOCA mission is a NASA recognized XISP-Inc commercial mission proceeding under a combination of existing and pending NASA Space Act Agreement authority as well as evolving commercial, university, and non-governmental organization agreements.

What is the problem being addressed?

XISP-Inc has hypothesized that in order to make near realtime state models real for a significant number of applications the order of the problems to be solved must be reduced to something tractable. The proposed approach involves:

1) Breaking up problem space into many sub-problems suitable for parallel processing
2) Focusing on the sub-problems that matter
3) Using initial conditions, boundary conditions, symmetry, known geometry, established datums, etc. to further reduce complexity

The key is to propagate constraints as rapidly as possible.

N-Dimensional interaction problems do not have to be intractable.

With appropriate metadata, transforms can be applied:

1) data is a set of ordered symbols,
2) data in context is information, and
3) information in perspective is knowledge

Problems of interest can be recast and structured as a LISP transform:

(Items (Attributes (Values)))

They can then be modeled as a set of process flow problems.

Inference driven constraint propagation can then be applied to reduce the generalized solution space to a computationally tractable scale.

The structure and ordering of knowledge makes a very real difference with respect to tractability of any proposed solution:

1) systems-of-systems can be bounded as a finite set of state transitions,
2) systems can be modeled as a set of flows across defined interfaces,
3) a taxonomy of flows can be defined as either energy, mass, or information and then further subdivided into individual types, and
4) each type of flow can be defined by a specific set of qualitative and quantitative attributes, independent of the source and terminus.

Each set of characterized flows can be associated with corresponding states and allowable transitions as shown in Figure1 System/Subsystem Flow Taxonomy[6,7].

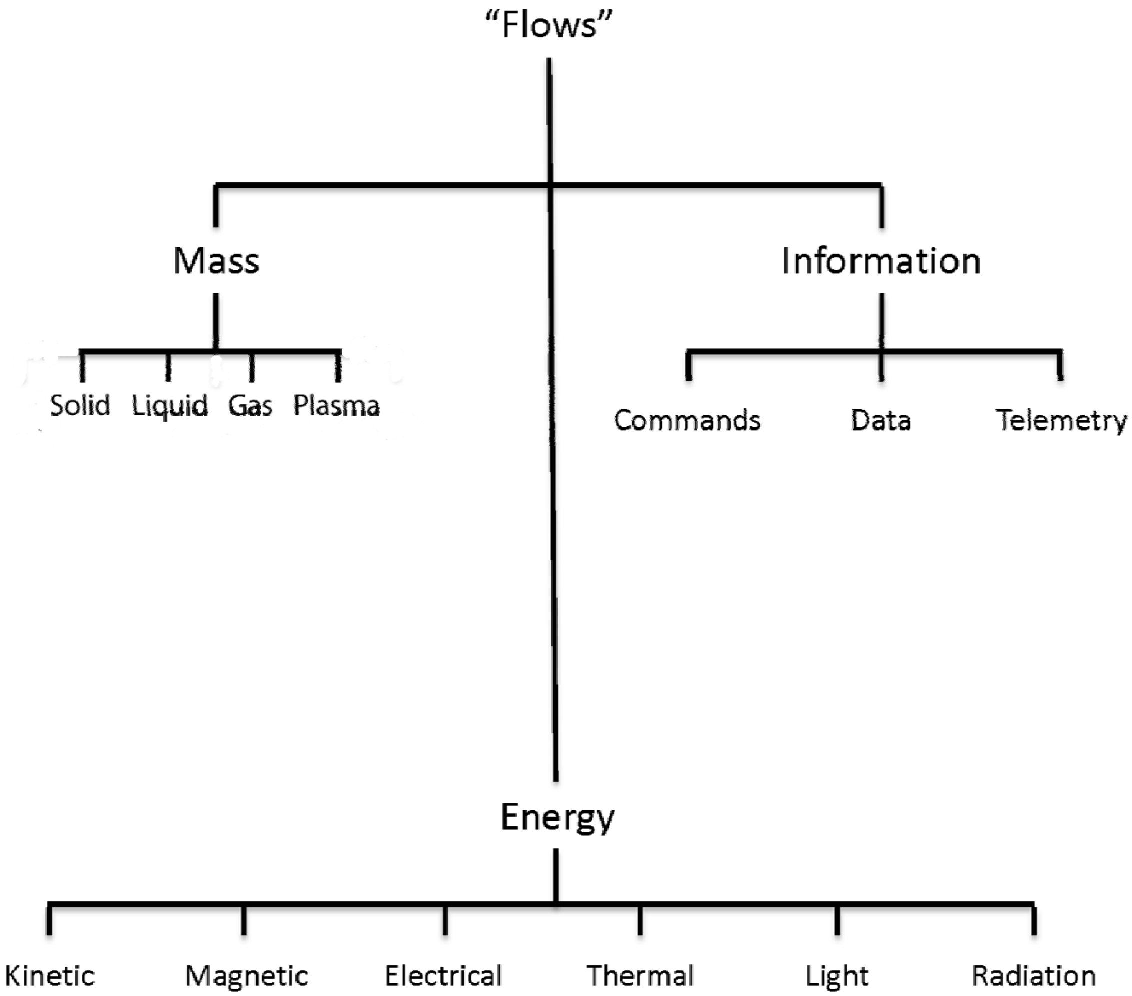

Figure 1. System/Subsystem Flow Taxonomy

What is the relevance of the problem to NASA and others?

The NASA ARC Open MCT Web is the web based modular programming environment that is being enhanced by XISP-Inc to incorporate near realtime state model extensions.

This work is germane to the NASA ARC / XISP-Inc Space Act Agreement on Management Operations Control Applications (MOCA) and an overarching Space Act Umbrella Agreement under negotiation between NASA Headquarters and XISP-Inc.

A primary mission of XISP-Inc is to develop cooperative arrangements with different parts of NASA and different industry partners. The early implementation of a readily extensible near realtime state modeling capability on ISS could prove to be enhancing if not enabling technology for a wide range of technology development, demonstration, and deployment missions.

The ISS is an extraordinary resource that can be leveraged to dramatically lower the cost of space solar power technology development, demonstration, and deployment.

MOCA Supported Missions

1) Team Alpha CubeSat (ACS) NASA Cube Quest Challenge
   a. Operations of 6U Cubesat
2) Space-to-Space Power Beaming (SSPB)
   a. Effective use of radiant energy beam components
3) Interoperable Network Communications Architecture (INCA)
   a. Testing Delay/Disturbance Tolerant Networking (DTN) with real world requirements
   b. Pervasively networked DTN gateway
4) Systems Control Through Advanced Algorithms (SCTAA)
   a. improve microgravity, decrease propellant use, and facilitate operations
   b. Demonstrate adaptive control using state models
   c. Multi-vehicle synchronization & payload control
5) Advanced Vision and Task Area Recognition (AVaTAR)
   a. Support mutable locus of control between teleoperation and autonomy on a shared control basis

XISP-Inc has brought together an innovative partnership to accomplish technology development work in this area including both government, commercial, university, and non-profit sectors. Many formal letters of interest have been submitted to NASA and/or XISP-Inc and are available on request.

This mission starts with the development and demonstration of a prototype parametric model for unbundled power systems for spacecraft sustained free flyer/surface operations as well as propulsion. This model enables collaborations with the NASA ARC Mission Control Technologies Laboratory and other interested parties. This work has provided an opportunity to craft a viable basis for establishing a confluence of interest between real mission users and the technology development, demonstration, and deployment effort.

III. Experiment Outline

This work begins with a top level view of the subsystems/functional components of a spacecraft electrical power system. There is a need to structure and order the knowledge of what is known, as well as what is known to be unknown in order to make this analysis tractable.

A. MOCA Initial Mission Objectives

The MOCA initial mission objectives are:

1) Defining and prototyping parametric state models for integrated end-to-end mission operations control applications.
2) Implementing the parametric state models for technology development and demonstration mission prototypes, test and flight articles.
3) This effort includes the incremental, iterative, and recursive development of near real-time state models of all the supported mission components operating within the MCT framework/environment

B. MOCA Initial Products for Supported Missions*

For the purposes of this work there four identified initial products for each supported mission:

1) Development of a paper model and individual element protocode.
2) Development of functioning individual element models and an end-to-end model protocode.
3) Optimization of individual element models and a functioning end-to-end model.

4) Testing of the optimized end-to-end model and individual element models in mixed modes (protoflight hardware and software with simulation as needed).

   * MOCA progress for each supported mission is being driven by the status and schedule of each mission and the availability of resources.

C. MOCA Supported Mission General Status

For the purposes of this work we have identified initial products for each supported mission
The experiment objectives that we have defined for this work are:

1) MOCA extended activities will focus on actual on-orbit demonstrations and flight testing the efficacy of the near realtime parametric state models developed for the supported missions.
2) Follow-on activities will focus on assessing, reviewing, and establishing the efficacy of applying the near real-time parametric state modelling tools to other current and future technology development missions.

D. MOCA Technology Development

For the purposes of this work we have defined the scope of the technology development involved to include:

1) Knowledge Base on Mission Control Technologies
   a. Significant Actors/Interested Entities
   b. Intellectual Commons
   c. Prior Art
      i. Patents & Patents Pending
      ii. Trade Secrets
   d. Known Unknowns
2) End-to-End State Models
   a. System/Subsystem
      i. Characterize the system/subsystem in a near realtime state model
      ii. Optimize the system/subsystem for performance based on application
      iii. Operationalize the system/subsystem by defining and encoding the performance envelope and operating rules.
   b. Spacecraft Systems-of-Systems
      i. Mission operations control

E. MOCA Technology Development

For the purposes of this work we have defined the scope of the technology demonstation involved with applying MOCA to:

1) Radiant Energy Beam Management
   a. Characterization of the radiant energy beam
   b. Optimization of the radiant energy beam
   c. Operationalize the radiant energy beam
2) Test Bed Operations
   a. Near Field/Far Field Test Bed
   b. Loosely Coupled Modular Structures Test Bed
   c. Propulsion Augment Test Bed
   d. Platform Infrastructure Technology Test Bed
3) Rectenna Design
   a. Differentiation and performance characterization by size
   b. Differentiation and performance characterization by type
   c. Differentiation and performance characterization by build method
4) Flight Test Article & Flight Support Equipment Management Operations
   a. Modular Small Space Craft (e.g., DSI (3U), Alpha CubeSat (6U), etc.) Interfaces
   b. Trajectory Insertion Bus Interfaces
   c. Spacecraft Deployment Interfaces
   d. Spacecraft Recovery Interfaces
   e. Logistics Carrier Augmentation Interfaces

F. MOCA Technology Deployment

For the purposes of this work we have defined the scope of the technology deployment involved to include:

1) Team Alpha CubeSat (ACS) NASA Cube Quest Challenge

a. NASA recognized team in good standing.
b. Successfully completed PDR, pressing to CDR for this fall.
c. Currently 95%+ volunteer effort supported by XISP-Inc.
d. System-of-systems view with drill down.
    i. systems => subsystems => components => interfaces => flows

2) Space-to-Space Power Beaming (SSPB)

a. NASA recognized XISP-Inc commercial mission.
b. Flight articles based on ACS & BitSat design from DSI.
c. Public/Private implementation team forming up.
d. CASIS integration support, Commercial Cargo, and ISS resource allocation requests in development.
e. End-to-end space-to-space radiant energy beaming characterization.

G. **Interoperable Network Communications Architecture (INCA)**

a. NASA recognized XISP-Inc commercial mission.
b. Flight articles based on ACS & BitSat design from DSI.
c. Public/Private implementation team forming up.
d. CASIS integration support, Commercial Cargo, and ISS resource allocation requests in development.

Near realtime characterization of the Quality of Service (Performance, Availability, and Security) for a single defined function.

H. **Systems Control Through Advanced Algorithms (SCTAA)**

a. Ongoing technology development effort aligned with the NASA Payload Opportunities Program.
b. EXOS Aerospace is an XISP-Inc teammate cooperating and collaborating on XISP-Inc missions (e.g., MOCA, SSPB, INCA, and AVaTAR).

Near realtime state model of the star tracker data acquisition, state data processing, and Reaction Control System command string generation for precision pointing.

I. **Advanced Vision and Task Area Recognition (AVaTAR)**

a. Nascent mission opportunity which could leverage near realtime state modeling capabilities that meet real mission requirements as a foundational technology for evolving space automation and robotics capabilities.
b. Near realtime state model of DEXTRE and dynamic world model of the task area and the it's intersection with the environment.

Enhanced MCT is intended to provide virtual control centers for all supported missions.

IV. Reality Check

Reducing the number of perceived “impossible things that have to be accepted before breakfast”* is a way of incrementally disabusing people of unfounded notions.

Doing something real with the technology that is of demonstrable value can help to establish the confluence of interests necessary to mature the technology for more advanced applications.

* Allusion to “Alice in Wonderland” by Lewis Carroll. "Alice laughed: "There's no use trying," she said; "one can't believe impossible things." "I daresay you haven't had much practice," said the Queen. "When I was younger, I

always did it for half an hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."

V. Mission Team

The following organizations, entities, and/or individuals have notified XISP-Inc of their interest in cooperation/collaboration with respect to this mission:

A. Commercial Entities

1) Xtraordinary Innovative Space Partnerships, Inc. - Gary Barnhard, et.al.
2) Deep Space Industries, Inc - Daniel Faber, et.al.
3) Center for the Advancement of Science In Space (CASIS) – David Zuniga, et.al.
4) Nanoracks Inc. – Chad Brinkley, et.al.
5) EXOS Aerospace – John Quinn, et.al.

B. Universities:

1) University of Maryland Electical & Computer Engineering Department – Emily Lathrop
2) University of Maryland Space Systems Lab – David Akin, et.al

C. Government Agencies:

1) NASA Headquarters Human Exploration & Operations Mission Directorate
    a. Advanced Exploration Systems Division, Jason Crusan, et.al.
    b. Space Communications and Navigation Office, Jim Schier, et.al.
2) Multiple NASA Centers will have some cooperating role – NASA ARC, et.al.

D. Non-profit Organizations:

1) Space Development Foundation
2) National Space Society

E. Consultants/Advisors:

1) Paul Werbos
2) David Dunlop
3) Joseph Rauscher

Multiple other commercial, educational, and non-profit organizations have expressed substantive interest in cooperation/collaboration with respect to this mission and are actively negotiating their potential role with XISP-Inc.

VI. Next Steps

MOCA is a XISP-Inc commercial mission recognized by NASA. NASA is participating through a combination of in-place (NASA ARC) and proposed (NASA HQ) Space Act Agreements. Formal request for support is under review with CASIS. NASA direct support to accelerate and/or add additional milestones when opportunities emerge is being negotiated. MOCA is intended to be a foundation for moving forward with the evolving XISP-Inc mission set.

Additional partners/participants are being sought in the commercial, academic, non-profit, and government sectors.

Opportunities for international cooperation leveraging the ISS Intergovernmental Agreement are being explored and developed. Use of ISS helps ensure that this is an international cooperative/collaborative research effort.

VII. Conclusion

Successful demonstration of a near realtime state modeling capability integrated with the MCT Open Web software suite paves the way for it's use for a wide range of Earth facing, space operations/development, and space exploration applications. By supporting the virtualization of mission operations control it can help to reduce the perceived cost, schedule, and technical risk of technology development missions.

An incremental investment in the development of near realtime state modelling capabilities that meet real mission requirements can provide a foundational technology for evolving space automation and robotics capabilities.

This work can deliver:

1) reduced cost, schedule & technical risk,
2) mission enhancing technology, and
3) mission enabling technology.

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