Technology Development Agreements
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Rover Technology Integration--CLARAty

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UPOI:			

1. Task Management

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JPL Program Office

Prog/Proj Management Organization (PPMO)	Prog/Proj Implementing Organization (PPIO)
6010 Mars Technology Program A Science Program 1.0 Focused Technology Program 1.3 Mars Science Laboratory 1.3.3 MTP Technology Infusion	6700 Mars Science Laboratory A Science Program 1.0 Focused Technology Program 1.3 Mars Science Laboratory 1.3.3 MTP Technology Infusion

Sponsoring Organization	Implementing Organization
Mars Technology Program 1.3.3 MTP Technology Infusion	3474 TELEROBOTICS RESEARCH & APPS

Period of Performance	Unique Project Number (UPN)
November 2002 to September 2005	979 - MARS SMART LANDER

Charge Accounts

Proj #	Proj Name	Task #	Task Name
102159	---	06.05.01	---

Competed/Directed Funding	JPL Technology Taxonomy
	15 Planetary Access 15.5 Unified Software Systems 15.5.5 Multiple Applications

2. Description

2a. Description and State of the Art (SOA)

The CLARAty (Coupled Layer Architecture for Robotic Autonomy)task will continue the development of the integrated robotic architecture, which was conceived and documented by this effort in FY00. CLARAty is a unified and reusable robotic software that provides basic functionality and simplifies the integration of new technologies for future missions. CLARAty is designed for the integration, validation, and maturation of various research technologies. It is targeting to solve three separate encumbrances to the advancement of intelligent robotic systems for space. First, is the lack of a common robotic software architecture that will provide a framework for technology integration. Without this framework, research teams have been hampered by the need for re-implementing and testing all system functionality on smaller, non-flight-like robotic platforms. Researchers often lack software systems which drive their problem solving by accurately reflecting flight complexities. Second, is the lack of a common software architecture spanning parallel research efforts. Without this, each effort is weakened by having to apply some portion of its limited resources to solving all subsystem problems, instead of leveraging solutions from outside their immediate effort. Third, is the disconnection between work performed in the Artificial Intelligence and Robotics fields. Separate work on problems solutions and software for these fields has commonly resulted in a patchwork of software implementations that never realize the potential of each of these domains, and what they can provide for each other.

CLARAty is a collaborative effort among two Division at JPL, NASA Ames Research Center, Carnegie Mellon University, and University of Minnesota. It also draws on expertise and contributions from participanting universities within the Mars Technology Program (MTP). CLARAty builds upon decades of robotic experience at JPL.

CLARAty has two layers: a Functional Layer and a Decision Layer. The Functional Layer of CLARAty provides basic generic functionality for robotic systems. It is an object-oriented software architecture that represents the robotic system as a set of abstract components that can be attached to real hardware components or virtual simulated components. It provides the basis set of functionality for the robot, and encapsulates this functionality at various abstraction levels. The use of object-oriented abstractions enables these solutions to span related system components, even across disparate systems, thereby reducing future development efforts. The Decision Layer is a model-based representation of the system and interacts with the Functional Layer at various levels of granularities. The Decision Layer is the home for artifical intelligence software components.

2b. Objectives

The primary objective of this task is to provide a common software test bed for the integration and validation of component technologies which are candidates for use by the MSL and future missions. CLARAty provides the framework to enable the comparison and validation of competing technologies for down selection by the project. The "Long Range Traverse Validation" task and the "Instrument Placement Validation" task characterize the performance of various technologies integrated into CLARAty. The results of these tasks will help the project evaluate the various technologies and the conditions under which they operate.

Technologies captured from the competed MTP program are integrated into CLARAty's packages and extend current robotic state-of-the-art available for all robotic researchers within JPL and among other program participants. By providing interoperability on various heterogeneous platforms, we will identify the relationship between the algorithm's performance and the robotic system configuration. The capturing of the robotic technologies in an integrated framework will facilitate the migration of multiple technologies to flight.

This task will continue the design and development of the various domain packages that will be adapted to the various existing and planned robotic platforms. This includes the continued design, evolution, and maintenance of various packages. This iterative process will mature domain components by capturing the knowledge and expertise of various technologists of the various sub-specialties in the robotics field. The integrated framework is a forcing function that addresses architectural issues of the various domains in a tightly integrated system, which will result in improved intelligence and robotic behavior. The packages in the CLARAty Functional Layer include instrument placement, manipulation, navigation, locomotion, vision, sensing, path planning, science, simulation, pose estimation, communication, motion coordination, motion control, generic I/O, hardware device drivers, and the various adaptations of these packages to each of the rovers: Rocky 8, Rocky 7, K9, FIDO, FIDO II, and ROAMS simulation. The packages in the Decision Layer include planner, executive, scheduler, rover models, and communication packages. We will continue to develop tighter integration with the Decision Layer, Functional Layer and simulation.

We will develop and extend the functionality of the architecture to meet the needs of researchers at JPL, Ames Research Center, Carnegie Mellon University, and other Universities that are part of the Mars Technology Program.

In FY04, we integrated and delivered for validation the following technoligies:
- Stereovision with CAHVORE camera model
- The MTP competed 2D visual target tracking
- The Morphin navigation algorithm

Additionally in FY04, we integrated and tested the following algorithms:
- The Drivemaps navigation algorithm
- The MTP competed wide baseline stereo
- The MTP competed wheel visual sinkage algorithm

In FY05, we are integrating and delivering for validation the following algorithms:
- The "Grid-based Estimation of Surface Traversability Applied to Local Terrain" (GESTALT) navigation algorithm that was deployed on the Mars Exploration Rovers.
- The competed 2D/3D tracking algorithm from various cameras (panoramic, navigation, and hazard) with camera hand-off among all pairs.
- The 6-degree-of-freedom Extended Kalman Filter (6DOF EKF) estimation algorithm (to be delivered in FY06). This will include the integration of the full degree-of-freedom kinematics of the rocker bogie mechanism developed under the competed Navigation on Slopes tasks.

Additionally in FY05, we will continue work on developing a mechanism model class structure to integrate mobility and manipulation mechanism representation and to enable the support of legged robotic systems. We will develop generic algorithms to support several different kinematic solutions. We will also develop an automated build, test, and release process for key CLARAty modules and support the newly awarded NRA tasks and all the current users.

In FY06, we will complete the integration and testing of the 6DOF EKF estimation technology and deliver this software for validation. We will integrate and test technology for stereo-based manipulation, rover-base placement and collision detection for manipulation. We will then deliver these systems for validation. We will also continue support the MTP competed tasks in their development of rover and robotic technologies and usage of CLARAty.

2c. Technical Approach

Our approach is to analyze and study each component technology that is being integrated. Depending on the technology, the legacy implementations it inherits, and the maturity of relevant CLARAty modules, the implementation of this technology will either fall right in, require some refactoring, or be encapsulated in the CLARAty architecture. A plan for the integration is proposed and discussed with technology provider. If the integrated technology results in changes to the domain framework, these changes are then discussed and examined by the working group responsible for that domain area. After several iterations and convergence on the design, an implementation plan is put forth and the division of labor between the currently funded technology provider and the CLARAty counterpart (s) is assigned. Once the technology has been captured with the proper documentation and data sets, a test suite is implemented that exercises the canned data set with known inputs and outputs to validated the integrated technology against the original implementation. This will insure that the CLARAty capture of the technology did not alter the algorithms on the first order. Sample demo programs are then developed by CLARAty to provide a guideline for the validation tasks for developing their comprehensive test plans and software suite. The technology module(s) are then released against the most recent CLARAty modules on which this technology depends. The integrated technology is then tested on one of the applicable rovers before delivery to the validation tasks. A web page is created that captures the executive summary of the technology, the various architectural and design documents and diagrams, the Functional Design Document, the processs for obtaining the code, the relevant references and later the validation results. In some cases, the same technology is tested of multiple rovers.

This task designs and develops the various domain packages that will be adapted to the various existing and planned robotic platforms. This includes the design, development, testing, refinement and redesign of the various packages. This iterative process will mature domain components by capturing the knowledge and expertise of various technologists of the various sub-specialties in the robotics field. The integrated framework is a forcing function that addresses architectural issues of the various domains in a tightly integrated system, which will result in improved intelligence and robotic behavior. The packages in the CLARAty Functional Layer include instrument placement, manipulation, navigation, locomotion, vision, sensing, path planning, science, simulation, pose estimation, communication, motion coordination, motion control, generic I/O, hardware device drivers, and the various adaptations of these packages to each of the rovers: Rocky 8, Rocky 7, K9, FIDO, and ROAMS simulation. The packages in the Decision Layer include planner, executive, scheduler, rover models, and communication packages. We will continue to develop tighter integration with the Decision Layer, Functional Layer and simulation.

CLARAty is designed to have two layers of control, Functional and Decision, which interact to provide robust and flexible implementation of intelligent operation. The Functional Layer is an object-oriented software representation of the robotic system and its basic capabilities. It provides low and mid-level autonomy capabilities for the robot. The system decomposition provides several layers of abstraction to provide various levels of reusability of the robotic software. The abstraction layers provide encapsulation of implementations and runtime models which vary from one system to another. Abstraction also harnesses system complexity and provides a system than can be extended and maintained. CLARAty employs well-understood and well-tested design paradigms and patterns in the software community to the rover and robotic domain problem. It provides a flexible system that can be extended and adapted to various rover and robots that will be developed in the future. This also allows the integration of technologies at various levels of the architecture.

The Decision Layer is designed to use the basis set of capabilities from the Functional Layer, for constraining and enabling solutions to problems it is given. The Decision Layer can utilize encapsulated Functional Layer capabilities with relatively high-level commands, or access lower-level functionality and combine it in ways not provided by the Functional Layer. The former is valuable when planning capabilities are limited, or under-constrained system operation is acceptable. The latter is valuable if detailed, globally optimized, planning is possible, or resource margins are small. The strength of CLARAty is that it supports both modes of operation.

CLARAty is designed specifically to incorporate the current state-of-the-art in mobile robot and manipulation control. CLARAty is geared for the design and maturation of novel robotic research technologies.

CLARAty collaborations include Ames Research Center, Carnegie Mellon University, and University of Minnesota who will be receiving bypass/subcontracts to continue their collaborations and co-development of the CLARAty framework

During the past five years, we have been designing, documenting, and implementing the architecture. We have implementations of CLARAty running on Rocky 8, FIDO, Rocky 7, K9 rovers and ROAMS simulation.

2d. Significance

The primary significance of CLARAty is that it provides a single integrated source for robotic software technology algorithms for migration to flight. CLARAty is critical for reducing the cost and duplication of infrastructure that would otherwise be needed for non-integrated and stand-alone robotic components. It also enables technologists to find a single source of robotic algorithms whose performance has been formally characterized through the validation process. This will clearly demonstrate whether new promised technologies can outperform the current baseline. If it does the new technology becomes the baseline.

CLARAty is a collaborative effort among two Divisions at JPL, NASA Ames Research Center, Carnegie Mellon University, and University of Minnesota. It encompasses contributions from MIT, University of Michigan, University of Washington, Ames Research Center and JPL as part of the MTP competed program. A new round of NRAs have been awarded to universities from future integration of technologies into CLARAty.

In addition to contributions from the MTP program, CLARAty has had contributions from the Intelligent Systems program in both the Functional and Decision Layers. CLARAty builds upon decades of robotic experience at JPL and its partering centers

The primary significance of CLARAty is that it provides and integrated repository of generic and specific robotic core capabilities enabling researchers to leverage prior work done in the field without the need for reinvention. CLARAty evolves the design of its packages through working groups composed of various leading researchers and technologists from participating centers. The product is a design and an implementation that will allow the interplay of various component technologies as well as the support of these technologies on various robotic platform with hetereogeneous hardware. This latter also includes support for real-time simulations.

2e. Comments

1. What is the functional relationship between your technology task and the following mission goals: 1) land safely, 2) land precisely, 3) go to a specific location (TBD km per command cycle), and 4) maximize science (including the number, duration, and quality of data samples)? For example: autonomous landmark mapping and correlation which allows for traverse of distances 50 meters or more, 30% faster than anticipated with MER.

Technology allows the comparison of different technologies for go to a specific location which can result in more robust and reliable traversing. It also allows for testing of various decision making capabilities that will resulting in maximizing science return

2. What is the impact on your development effort in if your funding is a) increased by 20% and b) decreased by 20%?

Reducing funding by 20% will push the schedule for maturing the various technology packages into the outer years. Technology might not be ready for the experimental validation tasks. Increasing by 20% will result on getting the packages completed sooner and allowing integration of additional technologies for comparison. This can have significant impact if new technology that are integrate prove to be superior.

3. What are the priorities of the different sub-tasks in your development effort?

Priorities in the list of importance

a) Integrate two different navigation algorithms into generic navigator structure. One of these technologies will be the MER navigation algorithm to serve as a baseline for comparison. Due to MER development constraints, the MER navigation algorithm will be encapsulated rather than refactored.
b) Develop and integrate technologies related to manipulation, mobility and manipulation coordination, precise instrument placement
c) Integrate better pose estimation algorithms and global path planning technologies into CLARAty
d) Define infrastructure for integrating additional decision layers

KEY DECISIONS: Key decisions made by the project that will affect this task is the selection of the appriopriate technologies for integration into CLARAty
Key decision made by the task is how to architect the system to support the integration of all technologies from the MTP program to allow interoperatility and comparison of various components (on-going)

4. What is the probably that your technology will be successful and the backup plan?

We are already having some success by the number of technologists integrating within CLARAty. The bottom line for success is:

Significantly reduce integration time of new technology software onto real robotic systems
Support multiple platforms with different hardware architectures
Provide a service that is enabling for technologists
Simplify the development/integrate/debug/test cycle for current and next generation NASA rovers
Have people other than the developers using and "like" the system

5. How is this technology dependent on other technology development efforts?

The CLARAty deliverables to the validation tasks depend highly on the architecture and quality of the receivables that CLARAty gets from the technology providers. It is not uncommon to have a number of iteration between the technology provider and the CLARAty engineers to define a feasible integration path for a given technology. The difficulty of technology integration greatly depends on the type of technology being "pulled in"

6. How would your technology scale for different system configurations and what is the impact on mass and power (if appropriate)?

The technology is designed to handle systems of various configuration and architecture. Impact on mass/power not applicable. However, impact on demonstrating functionality on a flight prototype can be significant for testing hardware functionality for a quick turn-around. We have adapted software for a new hardware architecture in relatively short periods of time.

7. What are the interfaces to your technology and are they standard (if appropriate)?

We define software interface at all levels of granularity. We are OS independent and can run under VxWorks, Linux, and Solaris.

8. Describe any out-of-house efforts related to this task and at what level of funding.

Level of funding for ARC is $125K and for CMU is $50K. CLARAty is a collaborative effort where our partners are becoming fluent in the design and are providing contributions to the design, technology and implementation. We are all working out of a shared repository with a solid infrastructure.

9. Provide the following procurement information:
a. What procurements are planned for the task and what is your acquisition plan?
b. Are these procurements competitive or non-competitive?
c. What is the level of procurements?
d. When will the procurements be executed?

Our development might require some upgrades to some of the rovers. Procurements will be about $50K for software development tools and hardware related items.

3. Schedule

3a. Deliverables

Deliverable	Deliver To	Date
1 Tracking and camera handoff from panoramic to hazard cameras on Rocky8	Instrument Placement Validation	Dec 2004
2 MER GESTALT R9.0 navigation algorithm working with ROAMS simulation	Long Range Traverse Validation	Jan 2005
3 MER GESTALT R9.1 navigation algorithm working with rover hardware	Long Range Traverse Validation	Apr 2005

4	Tracking and camera handoff from navigation cameras to hazard cameras on Rocky8	Instrument Placement Validation	Jun 2005

3b. Milestones

	Milestone	Date
1	Test Morphin in ROAMS using new CLARAty/ROAMs interface	Jan 2005
2	CLARAty operating on the new proposed FIDO upgraded hardware (new CPU and FireWire cameras)	Feb 2005
3	Develop error model for sun sensor (in support of 6DOF EKF estimator)	Feb 2005
4	Review and merge camera control software and update all adaptations. Test on Rocky 8 and FIDO.	Mar 2005
5	Develop mechanism model class to embody rigid body types and joints and actuation types	Apr 2005
6	Integrate full vehicle kinematics code into CLARAty (from Navigation on Slopes task)	May 2005
7	Develop an automated build, test and release process for key CLARAty modules	Jun 2005
8	Adapt FIDO motion control to Linux	Jun 2005
9	Develop error model for visual odometry (in support of 6DOF EKF estimator)	Jul 2005
10	Develop generic algorithms and interfaces for forward kinematics, Jacobian, and inverse kinematics	Aug 2005
11	Collect data to characterize ISIS IMU	Sep 2005
12	LEVEL I Milestone: Release 1.0 of CLARAty software that will include: - A set of well-defined, well-integrated, and documented modules that will focus on motion control and coordination, some elements of vision and stereo processing, and some elements of locomotion - An automated set of test programs to validate the above set - A nightly build system that will build the test daily for two targets: linux and vxworks - A complete Doxygen style documentation of the above set - A reasonably simple process for a new user to operate	Sep 2005
13	LEVEL II Milestone: An investigation into flight qualification - Identification of the elements that make CLARAty a non-flight qualified architecture and software implementation - Development a draft plan identifying the steps and effort levels for making CLARAty qualified for flight	Sep 2005

4. Funding

4a. Funding Distribution (Money OUT)

Year at TRL 6: 2005

Fiscal Year

	2003	2004	2005	2006	2007	2008
Technology Readiness Level	6	6	6			

Type	Who	2003	2004	2005	2006	2007	2008	Total to Complete
		"Work Year" per Year						
FTE	JPL Employee / Cat "A"	4.8	4.5	3.1				12.4
		($K) US Dollars						Total to Complete
JPL Funding		1134	1109	720				2963
Contracts to Industry	OphirTech		40	75				115
Grants to Academia	Carnegie Mellon	125	66	50				241
	U. Minnesota	48	54	30				132
Funds to Other NASA Centers	ARC	125	125	125				375
	Totals :	1432	1394	1000				3826
Totals Allocated by Program Office		1432	1403	1000	400			4235

4b. Documented Partnerships/Cooperative Agreements (Money In)

Type of Org.	Who/Comments	Amount ($K)
NASA	Bypass to ARC	125
Non-NASA	Contracts to: Carnegie Mellon University University of Minnesota	80

5. DNT Process

5a. Infusion Plan

In past years, we defined levels of infusing CLARAty design and functionality based on the robotics domain into MDS. Several approaches were explored ranging from the encapsulation of CLARAty functionality to the translation, including directly communicating integrated CLARAty designs to flight system.

We will continue to monitor the flight architectures for MSL and future missions and adapt our technology infusion plan accordingly. Further, for any delivered technology, we intend to have a working version of the software always be available in CLARAty for comparison, sanity checking and validation.

Finally, we will begin an investigation of flight software requirements to determine if CLARAty is consistent with such approaches.

5b. Reporting Plan

Weekly status reviews, Monthly Management Reviews, Quarterlies, MTP year end review, and other reviews, both oral and written, as necessary to support customers and program needs.

5c. Commercialization Plan

After the software environment reaches a certain level of maturity and CALTECH's rights with respect to intellectual property have been properly protected, this technology may be transferred to industry as appropriate to JPL's interests.

Although the software contributes to the NASA/JPL research efforts of robotic systems for surface operations in terrains located in outer space, there has been substantive research and development of robotic systems for non-military, commercial, industrial applications. CLARAty can be applied to robotic research systems at universities and other research centers. Additionally, it can be applied to industrial robotics as well as entertainment and educational robotic systems.

A separate task (RoverWare) is looking into the possibility of dissemination of some CLARAty modules for use by universities and future NRA awardees and found interest in these sectors.

6. References

[1] CLARAty Website
http://claraty.jpl.nasa.gov

7. NASA Technology Inventory

NTIDB ID	*not defined*
Software Only	No
Commercialization	No

7a. Technology Discipline Areas

Robotics

7b. Technical Application Areas

Planetary Atmosphere/Surface Systems

8. Approval

8a. Approval Status

Approval	Point Of Contact	JPL Org	Status
1 Task Manager	Issa A Nesnas Issa.A.Nesnas@jpl.nasa.gov 818-354-9709	3474	Submitted for Approval on 01/11/2005
2 Line 2	Homayoun Seraji Homayoun.Seraji@jpl.nasa.gov 818-354-4839	3474	Approved on 01/11/2005
3 Line 1	Richard A Volpe Richard.A.Volpe@jpl.nasa.gov 818-354-6328	3470	Approved on 01/11/2005
4 PPIO (Sub-Program)	Paul S Schenker Paul.S.Schenker@jpl.nasa.gov 818-354-2681	3400	Approved on 02/16/2005
5 PPIO (Program)	Suraphol Udomkesmalee Suraphol.Udomkesmalee@jpl.nasa.gov 818-393-4724	3401	Approved on 02/16/2005
6 PPMO Concurrence	Suraphol Udomkesmalee Suraphol.Udomkesmalee@jpl.nasa.gov 818-393-4724	3401	

8b. Notes

None