JERICO Evaluation Testbed

The DREAMS System

DISTRIBUTED ROBOT&AUTOMATION ENVIRONMENT MONITORING SUPERVISION

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ABSTRACT

In order to prepare future automation and robotics missions in space and to get confidence in the selected technology and development approach, **DREAMS** System demonstrates and validates the ESA robot monitoring and control technologies, which are enabling for future, unmanned Space missions. The target applications are relative to payload manipulation/inspection using classical rigid robot manipulators; the tasks are payload installation/removal, samples exchange, payload inspection, etc. The **DREAMS** System has been developed by TRASYS Space and installed at ESTEC laboratories to operate the JERICO Evaluation Testebed. Developments have been carried out in JAVA to assure the easiest portability between working environments.

1. INTRODUCTION

For automation and robotics missions in space ESA has chosen the following technologies:

1. Use of off-line programming as basis of the specification/validation of the robotic tasks;
2. Use of calibration to cope with positioning inaccuracies;
3. The Interactive Autonomy as operational mode of execution;
4. Remote and distributed control;
5. Integrated and user friendly programming environment,

here after briefly described.

1) Off-line programming Following this programming methodology all the positions that a robot must reach during the experiment execution are fixed and defined a priori. This methodology is often used when the environment of the robot is structured and known. Dedicated and very efficient robotics CAD tools support off-line programming.

2) Calibration technology Necessary conditions to succeed the experiments specified using off-line programming methodology are first, the availability of a robot with a very predictable Cartesian and dynamic behaviour, and second, an accurate knowledge of the working environment position. Therefore it is necessary to improve the absolute positioning accuracy of the robot with respect to its working environment, and to identify the real position of the environment with respect the robot. This can be achieved using advanced calibration techniques.

3) The **Interactive Autonomy operational mode** includes two aspects:

1. *Autonomy:* The nominal task of the robot is pre-programmed and its safe execution (e.g. against collision) is verified on ground. Once the task has been validated a robot task file is produced and up-loaded to the robot controller for later execution. The robot task file is a high level description of the activities that the robot must perform. Low level control (i.e. automatic control feedback) is considered to be provided by the robot controller.

2. *Interactivity:* In case of anomalies or divergence between the expected experiment results and the actual ones, the possibility exists for an operator or a scientist to interact with the executed process. Those interactions provide the necessary flexibility for handling anomalies. The interactions are performed at task or action level making use of pre-programmed recovery sequences. Once the anomaly is solved, the operator may resume to the nominal experiment plan.

4) Remote and distributed control The need to control from the earth a robot in the space imposes the remote control. Moreover, in order to offer the possibility to various types of users, either experimented in robotics or scientists with no knowledge in the field, to run experiments by their home-bases, a distributed control will be necessary.

5) Integrated user friendly environment Presently, all the previous items are considered in the robotics community separately. *Their integration into a coherent, user friendly environment that guides the operator from the specification of the robotics operations to their validation and execution is one of the main challenges of this project*.

The experience gained by TRASYS using off-line programming methods and tools and Interactive Autonomy operational mode in the successful ESA/NASDA joint experiments, performed in the framework of the VIABLE project, have been considered on the design and implementation of **DREAMS** System to facilitate the operation execution.

The resultinng **DREAMS** technology and solution shall be re-usable for future participation in:

- EUROPA, in-orbit external robotics joint demonstration between ASI and ESA. EUROPA configuration would be similar to the one proposed for EuTEF. A manipulator installed on an Express Pallet Adapter would perform operations on external payloads;
- Payload Tutor (PAT), an ASI proposal to NASA for internal robotics. PAT has been proposed to NASA as a mean to automate operations on NASA Express racks. PAT is expected to reduce significantly crew workload;
- European Technology Exposure Facility (EuTEF), an ESA programme. Although EuTEF is a self-contained programme, the work performed on JET could prove the validity of the **DREAMS** system for EuTEF

The document is structured as follows.

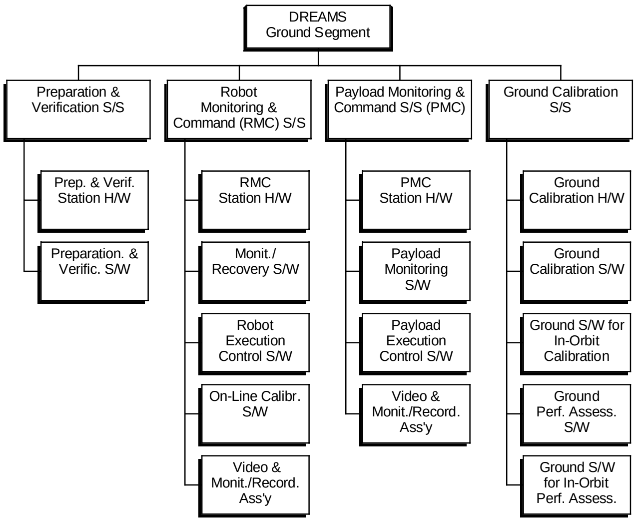
The second section provides the **DREAMS** architecture breakdown. We briefly describe the functionality of the s/s and their organisation in operational environments.

In the third section we present the different phases of the **DREAMS** system. The installation/development of the supporting S/W, the activity analysis programming and the MMIs design are the major concerns during this phase. We analyse these issues and we present the related developments in the framework of the JERICO Evaluation Testbed project as mature alternative for different Robot Monitoring and Control space missions.

Conclusions and remarks will be given in the last Section.

2. DREAMS ARCHITECTURE

The **DREAMS** System consists of the H/W and S/W necessary:



DREAMS Architecture Breakdown

1. To provide the users of the ground segment with an *integrated robot programming environment* that supports the preparation and the execution of experiments in a methodical, reliable and user friendly way. The passage from the conception of the experiments to their execution will follow four phases: the pre-preparation phase, the preparation and validation phase, the utilisation phase and the contingency phase which are explained later on;

2. To enable different types of users to *remotely control* the robot facility. Users with sufficient robotics knowledge, using remote robot monitoring and command environments will be able to prepare, validate and run new or predefined experiments. Scientists, not expert in robotics, from their home-base, will be able to submit for execution predefined scientific experiments.

To fulfil the objectives the **DREAMS** ground segment consists of four s/s.

The **Preparation and Verification S/S** will provide the necessary H/W and S/W environment to prepare and verify all activities of the robot facility. A ground operator will be able to develop new activities or to instantiate predefined ones (e.g. move payload from nest x to nest y, etc) and to verify them by simulation with respect to pre-defined criteria (e.g. collisions, timing constraints, resource availability, etc).

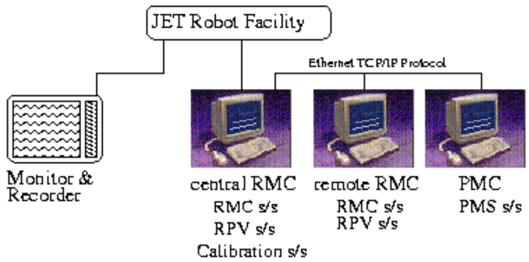
The **Robot Monitoring and Command S/S** will provide the necessary H/W and S/W environment to execute and monitor a complete activity plan. From the control point of view this s/s will support the start, the pause, the stop and the resume of activities. On the other side, for the monitoring purposes, the status of the activities execution will be provided as well as a predefined subset of the available telemetry (e.g. joint values, force/torque forces, …) necessary to conduct experiments. Camera snapshots or live video will be displayed to enhance user's perception of the robotic cell during operations.

The **Payload Monitoring and Command S/S** will provide the necessary H/W and S/W environment for a scientist, in a user home-base, to request for execution and to monitor pre-defined activities on the allowed payload. The command request (start-pause-stop-resume) is submitted to the Robot Monitoring and Command s/s for validation and execution. The monitoring will be done both using high level graphic simulation based on the telemetry data and possibly image(s) of the video down link.

The **Ground Calibration S/S** will provide the entire infrastructure to measure, calibrate and verify the performances of the manipulation s/s and the payloads s/s.

The considered sub-systems are regrouped in three categories of workstations in order to propose at users with different background the adequate environment to prepare and to execute activities in-site or remotely. Particularly,

- The *central RMC workstation* provides both the PV s/s, the RMC s/s and the Calibration s/s. Its main characteristic is that it is the only workstation that has direct access to the on-board robot controller;
- The *remote RMC workstations* include, as the *central RMC* workstation, both the PV s/s and the RMC s/s. But during the utilisation phase it does not directly address the on-board controller, using for this scope the functionality's of the *central RMC* workstation;
- The *PMC workstations* which provide the PMC s/s. During the utilisation phase they address the on-board controller through the *central RMC* workstation.



DREAMS ground segment composition

3. DREAMS Operation Phases

The *pre-preparation phase* of the **DREAMS** segment consists of a RMC station configuration needed to be addressed only once for each A&R application to support the system development and functioning. The *preparation and validation phase* consists in specifying and validating robotic activities (actions, tasks and compound tasks). During the *utilisation phase* the robotic activities are downloaded in the robot controller, and then, launched and supervised. In case of *contingency* recovery procedures could be prepared, validated and finally activated to handle the situation.

Pre-Preparation Phase

In the previous section we have seen all the subsystems of the **DREAMS** ground segment necessary to prepare, validate, monitor and control the JET robot facility and the associated payloads. The development and functioning of these subsystems require the installation/adaptation of supporting S/W, the presence of models of the robotic system, the analysis of the operations to be performed, and finally, the enhancement of the on-board robot controller with tasks implementing the required operations. The development of these models and programs are described in the next paragraphs.

World Model Generation

In particular, the **DREAMS** ground segment has the capability to model the geometry of the robot and its working environment by means of 3D CAD package (ROBCAD) and to update these models when needed. The structure of the world model is geometrically evolutive to support the update of the model after workcell calibration. A geometrical model of proximity, tactile and Force/Torque sensors is also provided. Robot and environment models could be imported/exported in the form in IGES format.

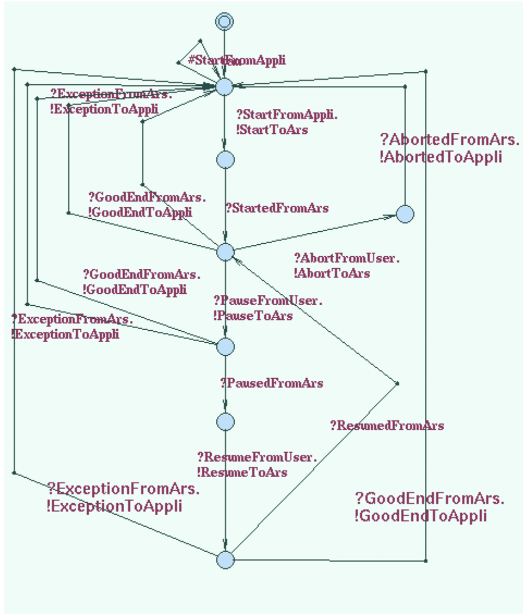
Programming Activities

For the pre-preparation of the **DREAMS** ground segment all the operations to be performed by the robot on the payloads must be programmed in form of activities. To this end two issues will be considered. First, the JET robot controller capabilities (SPARCO controller). Second, the result of the analysis and the identification of all the experiments allowed in the JET environment and of all the operations needed for each experiment.

The SPARCO controller implements a set of actions and tasks developed to support manipulation operations. Actions and tasks are described in a structured way in terms of: initial, boundary and termination conditions, typical non-nominal situations, and attributes associated with the environment, the manipulated subject and the robotic system. An action represents an elementary robotic operation while a task, as a composition of actions, represents a complex operation. For example, the PUSH_FORCE() action maintains a specified steady-state interaction force between robot end-effector and subject for a given duration; the INSTALL_IN() task uses PUSH_FORCE() action in order to install the specified subject in a port of a payload facility.

Particular attention will be paid on contingency situations handling. As far as possible, recovery procedures will be automatic in order to ensure the safety of the system and to enhance its autonomy. At least, if error occurs, the automatic positioning of the robot in a safe location will be assured. Some strategies in the case of the relax operation failure could be also automatic.

Flow of action in an implemented task including exception handling

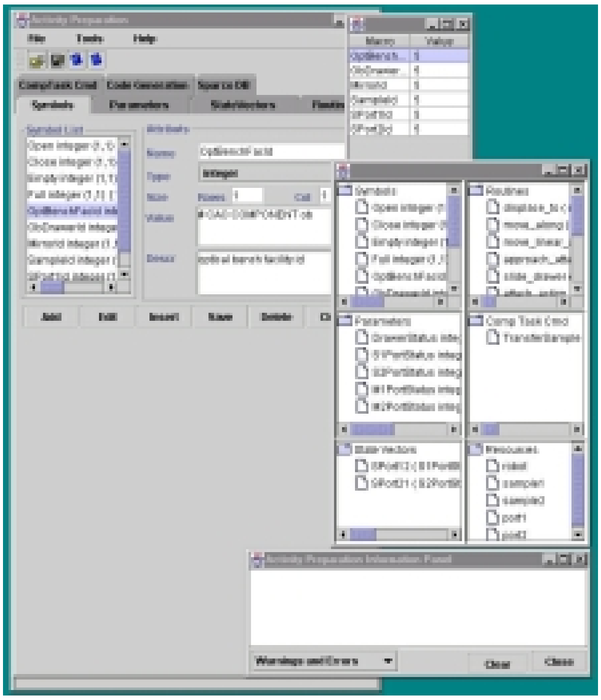


Preparation &Verification Phase

During the Preparation and Verification phase the Preparation and Verification s/s will provide the necessary H/W and S/W environment to prepare and verify complete system scenarios. This s/s, *during the simulation phase*, will offer to an operator, advertised in robotics, the means to enhance the capabilities of the **DREAMS** station by adding/editing new scenarios and verifying their validity. Notice that *during real activity and in the contingency phase* the P&V s/s will be accessible by the operator in order, if needed, to prepare/verify exception recovering scenarios. For the **preparation** two cases must be considered. Either a template activity that corresponds to the required scenario is already defined and exists in the activity library, or a new template activity must be defined and added to the library.

In the first case, the scenario can be prepared by selecting and instantiating a template activity from the library of the predefined template activities. The PV s/s shall allow the operator to assign a value, or a range, or a set of values to all parameters of the activity template.

In the second case, when a template activity corresponding to the required scenario



Preparation Control Panel

does not exists in the template activity library, the operator has first to type, in his preferred text editor, the program in the robot controller language that implements the required scenario. Then, he has to add it to the template activity library and to follow the previously described procedure to prepare the activity. An instantiated activity can be simulated to **verify** its conformity with respect to a predefined set of criteria that guarantees the safety of the operation. Such criteria are the reachability of the destination position, the collision avoidance and the availability of the required time and power resources. Before simulation, the PV s/s will allow the operator to associate to the instantiated activity the necessary information on the available resources (e.g. the remaining time and power). During simulation the above mentioned safety criteria are monitored to confirm the validity of the activity. In addition, abnormal situations could be forced to test the safety and robustness of robot programmes.

The simulation of an instantiated activity is performed by the A&R Emulator in connection with the ROBCAD software. The instantiated activity programme is downloaded and then interpreted and executed directly by a robot controller emulator via the Control Execution Panel. During simulation the state of the robot arm is continuously communicated to the ROBCAD software which then computes exteroceptive sensor information and returns them back to the emulator. Two types of exteroceptive sensors will be simulated: proximity sensors indicating the distance between the sensor frame and the target object, and the binary force sensor indicating when a contact between a particular part of the robot (e.g. the robot end effector) and its environment occurred.

Execution control panel for full qualified activities

Execution

The **Robot Command** consists in starting, aborting, pausing and resuming compound tasks. The **DREAMS** s/s gives the possibility to the operator to select a compound task from a library of compound tasks and to parameterise it. Once the validity of the parameter values checked, the operator could request to start the execution (real or simulated) of the compound task. During execution, the operator could abort the compound task, or pause it. Only a paused compound task could be resumed later on. The operator can request the start/abort/pause/resume of a compound task through a dedicated interface, the Execution Control Panel..

The Robot Monitoring consists in acquiring from the robot system the useful information needed both to undertake reactive command actions and to inform the operator of the evolution of the experiment. Current joint position values, the status of the running activity, the control mode of the onboard controller and the error status are a set of variables needed to be monitored during operations. The monitoring will be supported both using high level graphic simulation based on the telemetry data and the video down link.

The telemetry data will be distributed and displayed on the **DREAMS** 2D monitors and by the ROBCAD s/w in 3D. During the utilisation phase, simulation and real operations two robots will run in parallel. A "phantom" robot will show the simulated ROBCAD model executing simulated commands and generating simulated TM. This will run together with the ROBCAD model reflecting the actual robot status, through the TM coming from the real robot. The objective is to be able, during the operations, to compare and to foresee possible deviations from the planned scenario.

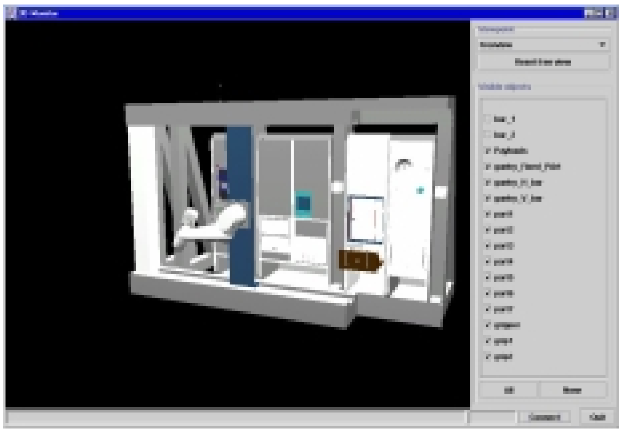
DREAMS MMIs

One of the important features of **DREAMS** is to provide the operators of the different working environments (central RMC, remote RMC and PMC) with an user friendly MMI-environment customised for their needs. All the system being developed in JAVA, the MMIs are uniform over all the working stations. Their design has been studied to be easy and clear for the operator how to:

- start up the working environment;
- create and verify activities;
- launch activities;
- monitor the robot in its environment and the payloads;
- monitor the telemetry;
- change through the operation phases;
- shutdown the system ;
- and cope with unforeseen situations.

To help the operator through the many windows, it is possible provide some of the working environments, especially the RMC, with more then one screen. The use of dedicated screens for e.g. full screen 3D animation or for visualisation of telemetry, eliminates the need for iconising or switching to other display levels to reach another MMI. All MMIs can be visible at all time if separate screens are used in ergonomic way.

DREAMS 2D Monitor System



DREAMS 3D PMC JAVA driven robot monitoring

DREAMS Experiments on JET

All experiments on the JET workcell are performed in *IA control mode*. High-level robot tasks will be executed autonomously without any operator interaction. One of the major features of the JET system will be the possibility to enhance the autonomy of the system by directly handling a predefined set of exceptions. In any case the operator will have the possibility to interact with the robotic system by starting, pausing, resuming and stopping the execution of the task. Contingency situations will be also provoked to illustrate that IA control mode is not contradictory to low level operations and that more intense interactions of the operator with the robotic system (as usually is needed in this type of situations) are possible.

The *calibration technology* will be also demonstrated on the JET environment.

The different experiments should be prerformed from geographically distant areas in order to demonstrate the *remote and distributed monitoring and control* capabilities of the JET ground segment. An operator, in preference not expert in robotics, will operate the robotic system from Belgium, using a PMC environment, while two other operators will use the remote RMC and central RMC environments at ESTEC (Noordwijk, The Netherlands).

We will particularly focus on the *integrated aspect of the proposed PMC and RMC environments*. Criteria to evaluate the degree of this will be the facility to launch and to use them, the ergonomic layout of the MMIs, the facility to change the operation mode from preparation to utilisation and contingency. These utilities have been implemented making the most of the experience acquired during the real robotic operations performed at NASDA in the framework of the VIABLE project.

4. CONCLUSIONS

The proposed **DREAMS** system provides the possibility to prepare future automated robotic missions in space and to get confidence in the selected technology and development approach. The **DREAMS** system gives the possibility to enhance the following technologies:

- Use of off-line programming as basis of specification/validation of the robotic task;
- Use of calibration to cope with positioning/mechanical inaccuracies in an integrated environment;
- Use of Interactive Autonomy as operational mode of execution;
- Use of remote and distributed control stations;
- Use of an integrated and user friendly programming environment for robotic experiements.

Portability and easy configurability will then offer to **DREAMS** system the possibility to large re-use in the future robotics space missions.

The DREAMS station and the JET testbed at ESTEC Laboratories