ERA, the Flexible Robot Arm

Phillippe Schoonejans, ESA,
Keplerlaan 1, 2201 AZ Noordwijk, NL. pschoone@estec.esa.nl, phone +31715655026, fax +31715654437

Marc Oort, Fokker Space
Newtonweg 1, 2303 DB Leiden, NL. m.oort@fokkerspace.nl, phone +31715245448, fax +31715245499

Abstract

The European Robotic Arm [ERA] is being built for use on the Russian Segment of the International Space Station. The project is commissioned by ESA as part of their manned-space program, with Fokker Space as Prime Contractor, and 23 companies from 7 European countries participating in the development of the arm. The ERA is scheduled to be launched by Space Shuttle to the ISS early in the next millennium. The system CDR was held at the same time as the I-SAIRAS conference. This paper focuses on the operational capabilities of ERA, ranging from fully automatic (monitored by a cosmonaut) to fully manual.

1. Introduction

The ERA system (Figure 1) consists of an arm, an EVA Man Machine interface, an IVA Man Machine Interface, a Refresher Trainer [RTR] and a Mission Preparation and Training Equipment [MPTE].

The ERA arm is a 11 meter, 6 Degree-of-freedom arm, whose most striking feature is the ability to cover large distance on the ISS by “hopping” from on basepoint (which supplies the power and communication interface) to another. Table 1 shows the ERA key performance parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Required performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>positioning open loop</td>
<td>&lt; 40mm, 1° [all axes]</td>
</tr>
<tr>
<td>positioning closed loop</td>
<td>&lt; 5 mm, 1° [all axes]</td>
</tr>
<tr>
<td>maximum speed</td>
<td>0.2 m/s</td>
</tr>
<tr>
<td>maximum transportable mass</td>
<td>8000 kg</td>
</tr>
<tr>
<td>clearance</td>
<td>0.9 m</td>
</tr>
<tr>
<td>stopping distance</td>
<td>0.15 m</td>
</tr>
<tr>
<td>outer loop control frequency</td>
<td>20 Hz</td>
</tr>
<tr>
<td>inner loop control frequency</td>
<td>300 Hz</td>
</tr>
</tbody>
</table>

Table 1: ERA required performance
Baseline Capabilities - Initial Tasks
- Installation, deployment of Solar Arrays
- Replacement of Solar Arrays
- Inspection
- Support/transfer of EVA cosmonauts

ERA Main Characteristics
- Symmetric anthropomorphic configuration
  - 6 DOF mission control, one joint locked
  - re locatable on basepalnts on ISS
- Operations can range from automatic control, through assisted manual to pure manual both for EVA and IVA
- Manual motions not with a Joy stick, but single degree of freedom motions with dip-switch or laptop command
- Advanced Synoptic Display for IVA operations to compensate for lack of direct visual contact

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As part of planning an ERA mission, the ground segment can combine all commands to the ERA Control Computer, and the characteristics of up to four payloads into one or more “files”, and load these into the on-board computer as dedicated Auto Sequences. The limitations in CPU capabilities prevent the Auto Sequences from acting as a pseudo programming language, with conditional branching or looping). The correctness of these sequences has been verified on the ground, and the supervisory task of the operator is thus limited to starting actions and to monitor the general progress of the mission. To compensate for the lack of direct visibility, the IVA operator has TV cameras and an (IVA MMI generated) geometrical world model available for monitoring. The operator has the choice to either explicitly activate each single command in an Auto Sequence, or the command the ERA to automatically a set of commands in sequence (a Task). At any time, the operator can take over command and continue manually, after which he can resume the Auto Sequence.

Below is an example of a Task in an Auto Sequence (Table 2). The first task could typically be executed at task level, the second one at action level. A snapshot of
the procedure for the EVA MMI cosmonaut, in the ISS Standard Ops Data Format is given in Table 3.

Table 3: Example of an operational procedure

   It is also possible to operate the ERA without the help of pre-planning by the ground. These operations use hard-coded Auto Sequences inside the ERA ECC, each of which are designed to complete a partial mission objective (see Table 4).

<table>
<thead>
<tr>
<th>Task 12 Preparatory</th>
</tr>
</thead>
<tbody>
<tr>
<td>113 Set Max Speed Discrete</td>
</tr>
<tr>
<td>325 Check Active Basepoint</td>
</tr>
<tr>
<td>328 Check Initial Pose</td>
</tr>
<tr>
<td>114 Set Payload Class</td>
</tr>
<tr>
<td>331 Download Frames</td>
</tr>
<tr>
<td>200 Go to Controlled Hold</td>
</tr>
<tr>
<td>304 Load Working Data Base</td>
</tr>
<tr>
<td>305 Enable New Data Base</td>
</tr>
<tr>
<td>322 Select TAF (Target BP, or PMU)</td>
</tr>
<tr>
<td>322 Direct Bus Command (Wrist TFS ON)</td>
</tr>
<tr>
<td>4000 Select Viewpoint</td>
</tr>
</tbody>
</table>

   Task 13 Transfer:
   107 Free Move |
   108 Single Joint Move |
   126 Pitch Move |
   203 Go to Shoulder Yaw Joint Hold |
   206 Go to Controlled Hold |
   208 Single Joint Move |
   203 Go to Standby |
   200 Go to Controlled Hold |

Table 2: An example of a part of an Auto Sequence

ER - EMMI ‘MENU’
Scroll ‘SEL AS’ to Center Window, then to Left Window
\( \sqrt{01} \) in Center Window
Scroll ‘01’ TO Left Window
Verify ‘START’ LED flashing
Press ‘START’ Switch for 2+ seconds
ERA STATE
\( \sqrt{01} \) in Center Window
‘TOP’ in Top Window
‘T013:01’ in Center Window
‘T018:02’ in Bottom Window

Table 4: Available Mini Auto Sequences in ERA

| 15 POPIN | popin screwdriver |
| 16 FIRMFLEX | firm/flex TFS |

The commands inside these Mini Auto Sequences are designed to be independent of the desired position for the arm and/or its payload. A selectable list of hard-coded coordinates of basepoints and payload mounting units, allows the operator to specify the final position without having to determine or type in coordinates. If a position is not in the list, the ERA can “build” a target position from the end-effector camera’s image of a standard reflective pattern which is located next to each Grapple Fixture.

The ERA Control Computer, and its counterpart in the IVA MMI, also keep track of the position of payloads moved within its model of the space station, thus keeping the on-board collision avoidance routines up to date, provided the objects are moved using ERA.

5. A flexible arm: Unplanned Operations in Fully Manual Mode
   If even the hard-coded sequences are not sufficient or usable, it is possible to move the arm manually using keys and/or switches (no joy stick). Both long motions (up to 10 meters) or short steps (10 mm, 1 degree) are possible. Motions can be commanded both in a frame of reference coupled to the arm, and one fixed to the ISS. As the motions of the arm happen under full control/responsibility of the operator, the rotations have been limited to one degree of freedom at a time. The arm can even be operated in this manner when the Russian Segment Central Post Computer (which is in charge of the communications between the MMIs and the ERA) has failed. The EVA MMI can be connected directly to the ERA bus, and commanded from there. If all else fails, mechanical overrides (using EVA) are possible as well, requiring no SW at all.
6. Conclusions
The ERA has been designed to cope with a wide range of operational conditions, from fully planned to unplanned manual contingency operations, thus making a truly flexible robot arm. Astronaut reviews of the MMI designs have shown that the ERA is operable and user friendly, at least as seen in simulated conditions. Man-in-the-loop testing planned next year will show to what extent this is true for the full system when a complete mission has to be executed.