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NET Remote Workstation

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KERNFORSCHUNGSZENTRUM KARLSRUHE

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Preface

The goal of this report was to set up a framework for the development and a first design proposal of the NET Remote Handling Workstation (NRWS). The NRWS represents the only interface for the tele-operator to the remote handling equipment and the working environment. Additionally the NRWS provides high level support software modules for operator assistance during the planning and preparational phase and during maintenance execution.

The first section of the report reviews the JET Remote Handling Workstation as the prototype of workstation for remote handling in fusion maintenance.

The second section covers the ongoing work in related areas of telerobotics. Newest trends in the area of general purpose workstations providing advanced operator support are reviewed to point out future developments which should be integratable into an open NRWS architecture.

In the third section the possible design alternatives of a NRWS are discussed.

The main section, the fourth section, presents a design proposal of a general purpose NET Remote Handling Workstation for fusion plant maintenance adaptable to different applications and designed as an open system with a modular architecture and clear interfaces guaranteeing incremental growth by stepwise integration of new man-machine interface modules and advanced high level operator support modules. This section defines a set of standard functional modules (features) supporting the operator. A set of additional interfaces facilitates software design, development, validation, and tests, and makes possible the integration of modules from a variety of sources.

The requirement definition document for the NRWS is found in the appendix A.

The backmatter includes a glossary of terms from telerobotics, data processing, and data communications.

This work has been performed in the framework of the Nuclear Fusion Project of the Kernforschungszentrum Karlsruhe and was supported by the European Communities within the European Fusion Technology Program as a study contract for NET.

For fusion plants fully remote maintenance concepts are favoured for costs as well as for safety and availability reasons. A remote handling workstation will be the only interface for the operator to the remote handling equipment and the working site. Based on the experiences at JET and review studies in related fields where workstations are used to control various kinds of processes a concept for a remote handling workstation providing an advanced tele-operator support tailored to NET/ITER needs was worked out. The goal of this NET study was to define the functionality of a remote handling workstation and its hardware and software architecture.

The remote handling workstation has to fulfill two basic functions: (1) to provide the man-machine interface (MMI), that means the interface to the control system of the maintenance equipment and to the working environment (telepresence) and (2) to provide high level (task level) supporting functions (software tools) during the maintenance work and in the preparation phase.

Concerning the man-machine interface, an important module of the remote handling workstation besides the standard components of man-machine interfacing is a module for graphical scene presentation supplementing viewing by TV. The technique of integrated viewing is well known from JET BOOM and TARM control using the GBsim and KISMET software. For integration of equipment dependent MMI functions the remote handling workstation provides a special software module interface.

Task level support of the operator is based on (1) spatial (geometric/kinematic) models, (2) remote handling procedure models, and (3) functional models of the equipment. These models and the related simulation modules are used for planning, programming, execution monitoring, and training. The workstation provides an intelligent handbook guiding the operator through planned procedures illustrated by animated graphical sequences. For unplanned situations decision aids are available.

A central point of the architectural design was to guarantee a high flexibility with respect to hardware and software. Therefore the remote handling workstation is designed as an open system based on widely accepted standards allowing the stepwise integration of the various modules starting with the basic MMI and the spatial simulation as standard components.

NET Fern-Arbeitsstation

Für Fusionsanlagen werden vollständige Fernwartungskonzepte bevorzugt, um Kosten zu sparen und um die Sicherheit und Verfügbarkeit zu erhöhen. Eine Fern-Arbeitsstation (remote workstation) wird dabei die einzige Schnittstelle zwischen dem Operateur und den Arbeitsgeräten bzw. der Arbeitsumgebung sein. Ausgehend von den Erfahrungen bei JET und einer Studie über vergleichbare Arbeitsstationen anderer Anwendungsbereiche wurde das Konzept einer Arbeitsstation ausgearbeitet, die dem Tele-Operateur fortgeschrittene Arbeitshilfen bietet. Das Ziel dieser NET-Studie war es, die Funktionalität und Architektur einer Arbeitsstation für die Fernwartung zu definieren.

Die Arbeitsstation für die Fernwartung hat zwei Aufgaben zu erfüllen: (1) Sie repräsentiert die Mensch-Maschine-Schnittstelle (MMS), d.h. die Schnittstelle zum Steuersystem der Wartungsgeräte und zur Arbeitsumgebung (Telepräsenz) und (2) sie stellt während der Wartungsarbeiten und in der Vorbereitungsphase Software-Werkzeuge bereit, die den Operateur bei aufgabenbezogenen Tätigkeiten unterstützen.

Ein wichtiger Modul der Fernwartungs-Arbeitsstation bezüglich der Mensch-Maschine-Schnittstelle (neben deren Standardkomponenten) ist ein Modul zur graphischen Szenendarstellung, der die Beobachtung der Arbeitsszene mit Hilfe von Fersehsystemen ergänzt. Diese Technik des integrierten Beobachtens ist vom JET-BOOM- und JET-TARM-Kontrollsystem bekannt, sie wurde dort mit den Systemen GBsim und KISMET realisiert. Für die Integration von gerätespezifischen MMS-Funktionen ist in der Arbeitsstation eine spezielle Software-Modul-Schnittstelle vorgesehen.

Die aufgabenbezogene Unterstützung des Operateurs bezieht sich auf die Planung, die Programmierung, die Ausführungsüberwachung (Monitoring) und das Training. Die Hilfen basieren auf (1) räumlichen (geometrisch/kinematischen) Modellen, (2) Modellen der Fernhandhabungs-Prozeduren und (3) funktionellen Modellen der Arbeitsgeräte und zugehörigen Simulatoren. Die Arbeitsstation stellt ein intelligentes Handbuch dar, das den Operateur durch die geplanten Wartungsprozeduren führt, wobei diese Führung durch bewegte Graphiksequenzen unterstützt wird. Für ungeplante Situationen stehen Entscheidungshilfen zur Verfügung.

Ein zentrales Ziel des architektonischen Entwurfs war es, eine hohe Flexibilität bezüglich Software und Hardware zu garantieren. Daher wurde die Arbeitsstation als offenes System konzipiert, das auf weithin akzeptierten Standards basiert und so die schrittweise Integration der verschiedenen Module erlaubt, wobei die MMS und die räumliche Simulation den Kern der Arbeitsstation bilden.

Acknowledgement

The work presented in this document is the result of many discussions and the collaboration with colleagues at various institutions. I would like to name especially T. Raimondi, A. Rolfe, L. Galbiatti, and A. Galetsas from JET for valuable discussion over a long period of time and collaboration during implementation of the graphics attachment GBsim and KISMET for the JET remote handling control. Without this collaboration the work would have been impossible.

For helpful and clarifying discussions during the review process I would like thank Clive Holloway and Mike Browne from the NET team.

Last but not least I would like to thank my colleagues at KfK for numerous discussions and reports on their research results.

List of Abbreviations

JET related

AB	Articulated Boom
AC	Access Hall
AH	Assembly Hall
CAMAC	Computer Automated Measurement and Control
CCTV	Closed-Circuit TeleVision
CODAS	JET Control and Data Acquisition System
GWS	Graphic Workstation
HC	Hot Cell
IVIS	In-Vessel Inspection System
JET	Joint European Torus
JRWS	JET Remote Workstation
KISMET	KInematic Simulator, Monitor, and programming Environment for Telemanipulation
LCU	Local control unit
MSM	Master Slave Manipulator
PoR	Point of Reference
RH	Remote Handling
RHCR	Remote Handling Control Room
RHCS	Remote Handling Control System
RHICS	Remote Handling Integrated Control System
RHWS	Remote Handling Workstation
ROLLT	Remotely Operated Low Level Transporter
SM	Servo Manipulator
SMMS	Servo Manipulator Master Station
TARM	Telescopic Arm (at JET)
TB	Tool Box
TP	Touch panel
TT	Turret Truck
VV	Vacuum Vessel

NET related

ABS	Articulated Boom System
ABT	Articulated Boom Transporter
BCS	Base Coordinate System
BHU	Blanket Handling Unit
BMM	Bridge Mounted Manipulator
BMS	Basement Manipulator System
BMT	Bridge Mounted Transporter
CCTV	Closed-Circuit TeleVision
CTUM	Contained Transfer Unit Manipulator
DHU	Divertor Handling Unit
EDITH	Experimental Device for In-Torus Handling
IVHU	In-Vessel Handling Unit
IVT	In-Vessel Transporter
IVVS	In-Vessel Vehicle System
LCU	Local control unit
LEC	Local Equipment Controller
LHM	Lower Hall Manipulator
LPHU	Lower Plug Handling Unit
LPM	Lower Plug Manipulator
MSM	Master Slave Manipulator
NCS	NET Control System
NRWS	NET Remote Workstation
OIF_M	operating interface for module
OIF_W	operating interface module for window access
RH	Remote Handling

RHCR	Remote Handling Control Room
RHCS	Remote Handling Control System
RHM	Reactor Hall Manipulator
WU	work unit (z.B. divertor handling unit)

General

C	C Programming Language
CAD*I	CAD Interface (Data Format for CAD Data Transfer)
IRDATA	Industrial Robot DATA transfer format
ISO	International Standardization Organisation
ISO/DIS	ISO Draft International Standard
ISO/OSI	ISO Open System Interconnection
FDDI	Fibre Distributed Data Interface
MAP	Manufacturing Automation Protocol
MMI	Man-Machine Interface
MMIM	Man-Machine Interface Management
MMS	Manufacturing Message Specification
TBD	to be defined
UNIX	Workstation Operating System from AT&T
UIMS	User Interface Management System
2D	two-dimensional
3D	three-dimensional

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Section 1. State of the Art: JET Workstation

1.0 Introduction

JET remote maintenance is based on a "man-in-the-loop" philosophy using bilateral, force reflecting, master/slave servo-manipulators. The MSM slaves and the various task suited end-effectors and special tools are positioned at the working sites by transporters. The remote handling operator, sitting in a control room, is linked to the working site by a camera system (enhanced by acoustic channels), graphical scene and data presentations, and various input devices. The central component in interfacing the operator to the remote handling system is the general purpose remote handling workstation which may be attached to the various remote handling equipment, providing a uniform standard interface.

The following chapters shall give a general overview over the tasks to be done and the available equipment to be controlled via the remote handling workstation. The section is based on personal communication with JET and related literature [1] [2] [3] [4] [5] [6] [7] [8] [9] [10][11].

1.1 RH Tasks

All tasks are classified as follows:

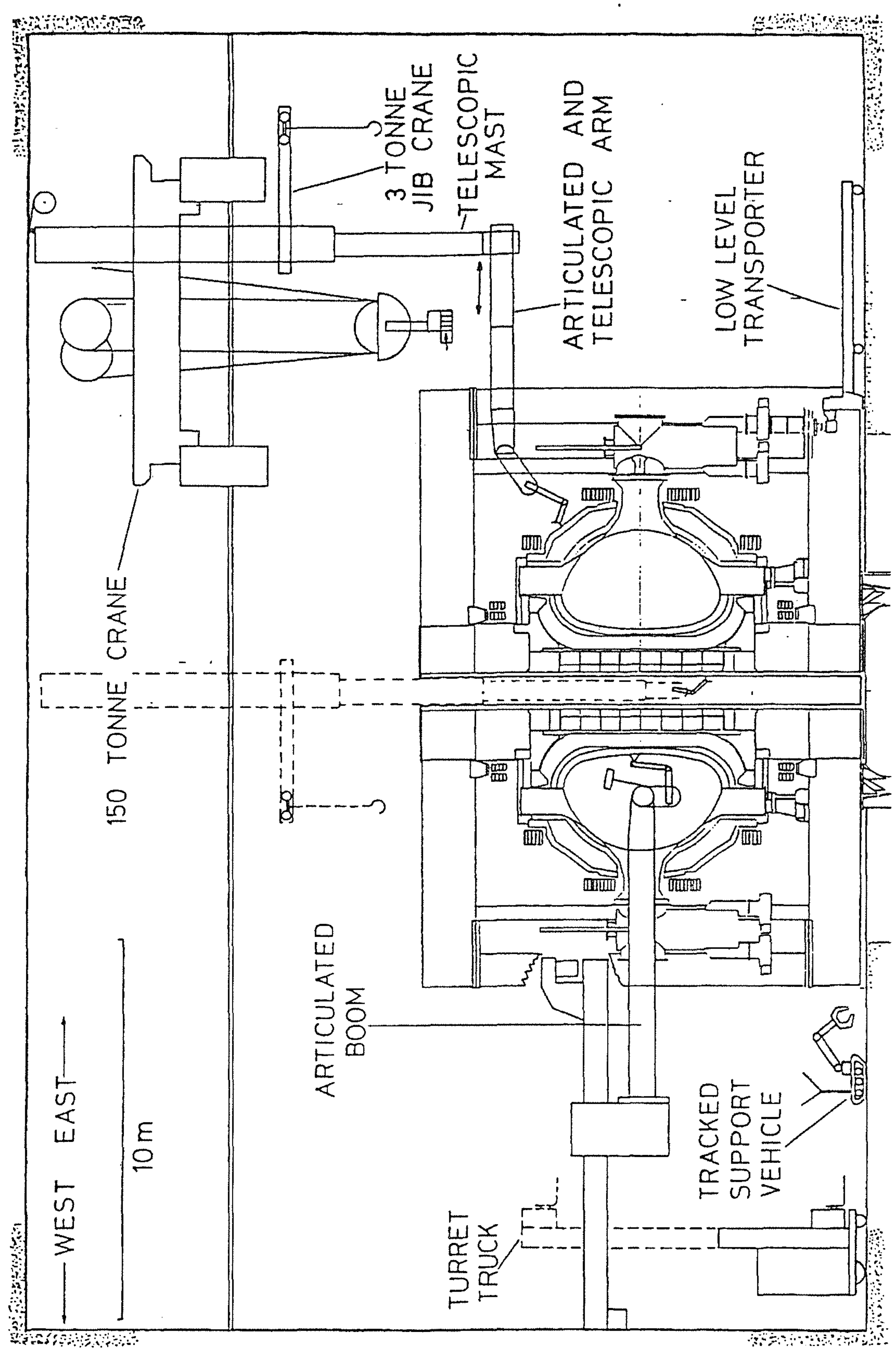
1. Certainly needed during JET lifetime and essential to continued operation or safety. RH equipment will be fully prepared.
2. Not expected, but necessary to continued operation of JET if need arises. Preparation cost balanced against probable saving in JET operation time.
3. Not essential to JET operation but continued use of component preferred. RH equipment will be developed only when required.
4. RH positively not needed.

The main tasks listed below are broken down in subtasks which are not subject of this chapter.

1. In-vessel
    - belt limiter exchange
    - antenna exchange
    - tile exchange
    - inspection (e.g. protection tile inspection)
    - others
2. Ex-vessel
    - Neutral beam injection system maintenance
    - octant removal/reassembly
    - inspection (e.g. vacuum vessel leak detection)
    - diagnostic system maintenance
    - opening of vessel
    - removal/reconnection of supply lines
    - others

1.2 RH Equipment

To perform these tasks several end-effectors and tools are provided which are carried to the work site by various transporters.



Source: JET

Figure 1. Remote Handling Equipment. Overall Pattern

1.2.1 Transporters

An overview over the different JET transporters and their environment is given in Figure 1 on page 4.

1. 150 t crane
   - 3 t JIB crane
   - telescopic mast with articulated and telescopic arm (TARM)
2. articulated boom (BOOM)
3. turret truck
4. tracked support vehicle
5. low level transporter

1.2.2 End-Effectors and Special Tools

The real maintenance work is done using various special purpose and general purpose end effectors and tools.

1. MASCOT-4 master/slave manipulator
   - bolt wrenches
   - bolt locking tab removers & fitters
   - tile handling tools
   - protection plate handling tools
   - bellow retractors
   - cutting tools (pipe)
   - welding tools (pipe)
   - alignment tools (pipe)
   - cutting tools (windows)
   - pulling tools (windows)
   - leak test tools
   - hand held camera
   - water wash tools
2. Grabber
   - AT housing shield
   - AT screen shield
   - Belt limiter shield
3. others

1.2.3 Viewing Equipment

- In-vessel inspection system (IVIS)
- Reactor hall fixed cameras
- Transporter mounted cameras
- MASCOT camera

2.0 Remote Handling Workstation and its Environment

The purpose of this chapter is to present all control system components with which the operator interacts directly performing remote handling tasks. This is needed because at JET the remote handling workstation is not the only interface to the control system. In so far this chapter describes all RH control system components related to the task control level of the control system.

2.1 The Remote Handling Control Room

In this chapter the direct environment of the JRWS is presented and discussed. The equipment of the room is shown in Figure 2 on page 8.

- 2 Servo-manipulator master stations mainly for controlling the boom MSM and the TARM MSM Each station is equiped with a RHWS to control the directly related equipment (e.g. cameras) and one GWS.
- 2 General Purpose RHWS which are intended to be used for various equipment.
- 1 supervisory RHWS
- Video equipment (e.g. recorder)
- Data base terminal

A very important problem which is still in discussion at JET is the problem-adapted selection of communication channels between operators and, if installed, the supervisor and the operators. Control room layout should be done in the light of communication needs between operators working in related areas.

The communication alternatives in discussion are:

- Direct communication between the operators, sitting near each other
- Indirect communication between operators completely separated using artificial communication channels as: microphone/head-phones, computer channels like keyboard/display/graphics. An operator may have access to the state of the related work via computer display.

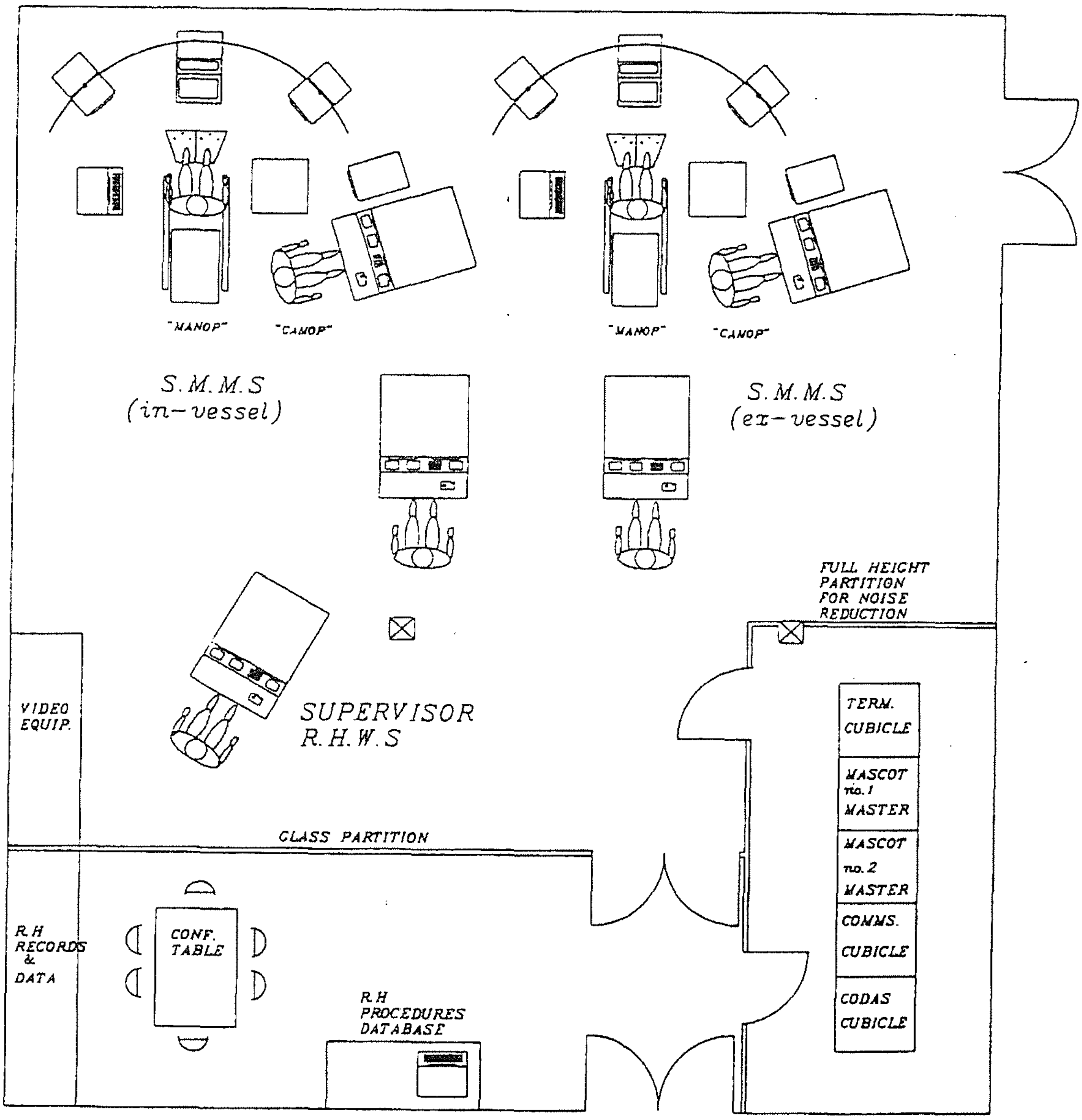
2.2 Remote Handling Workstation (RHWS)

The JET requirement of providing a rationalized type of man-machine interface through which any piece of RH equipment (except the Mascot MSM) is controllable leads to the design of the JET remote handling workstation. The general operating procedure is identical for all remote handling equipment being controlled. The workstation software guides the operator in configuring the MMI interface for a selected equipment. The RHWS is a general purpose workstation designed at JET using mostly existing software and hardware this means software and hardware primarily chosen for data acquisition and control. This general purpose workstation provides:

- Control and monitoring of any RH equipment in real time.
- A general operating procedure identical for all equipment thus minimizing the operator's training and errors.

The basic ideas which lead to this general purpose remote handling workstation were:

- One operating procedure and one type of interface for all RH equipment.
- Minimize the number of control devices in the control room.



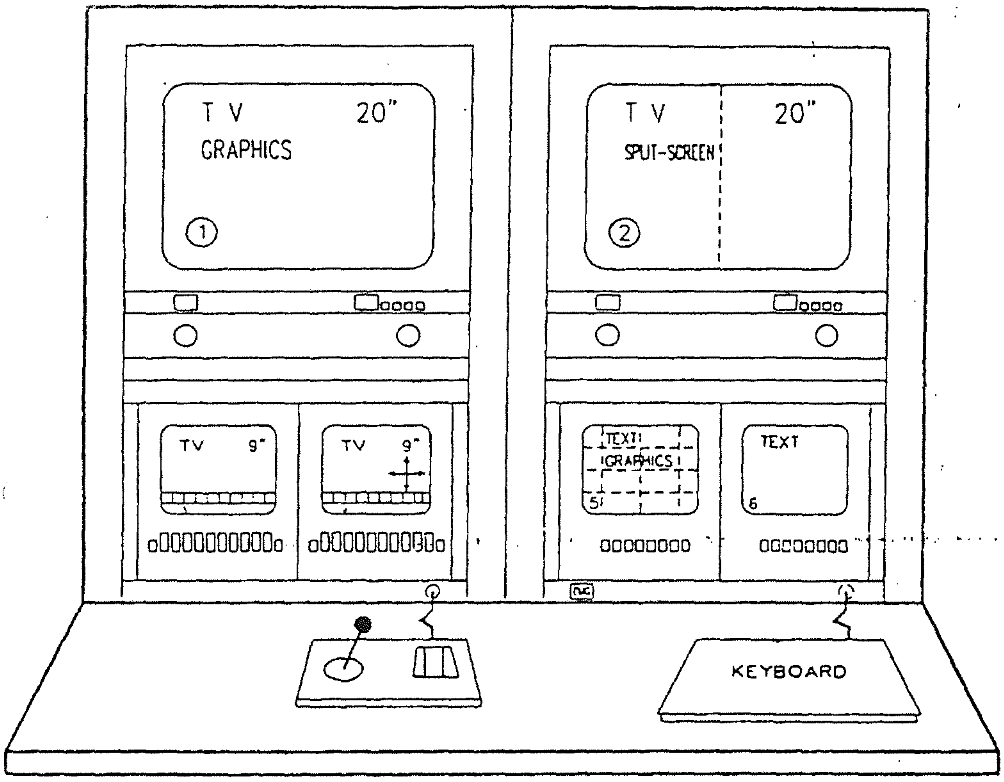
Source: JET

Figure 2. Remote Handling Control Room layout

2.2.1 User Interface Hardware

As shown in Figure 3 on page 9 the interface consists of the following building blocks:

- 2 20″ VDU for TV and graphics
- 2 9″ VDU for TV, text, and graphics
- 1 9″ touch panel for menu selection and control device re-use
- 1 computer terminal
- 20 programmable rocker switches
- 1 3-axis analogue joystick



Source: JET

Figure 3. Remote handling workstation. Layout

2.2.2 Functionality

The user support functions of the RHWS are, at the moment, limited to the following basic functions:

- Allocation of control devices (rocker switches, joystick) to RH equipment, especially cameras. This allocation is done via a hierarchical touch panel menu (Figure 4 on page 10).
- Monitoring of various information (e.g. welding current)
- Display of text instructions (schedules) to guide the operator through a procedure (planned)

Figure 5 on page 11 and Figure 6 on page 12 show a command overview available via the touch screen. At the end of each selection "tree" traversal the function keys are attached to the selected basic control functions. For example, if the operator wants to control the RF screen grabber by single joints he has to pick the touch panel fields BOOM, RF_SCREEN_GRABBER, SINGLE_JOINT one after the other and then he can control the motion of the equipment by the rocker switches and the joystick: with the rocker switches he selects the joints A0 to EE and with the joystick he then controls the motion of the selected joint (see also Figure 4 on page 10).

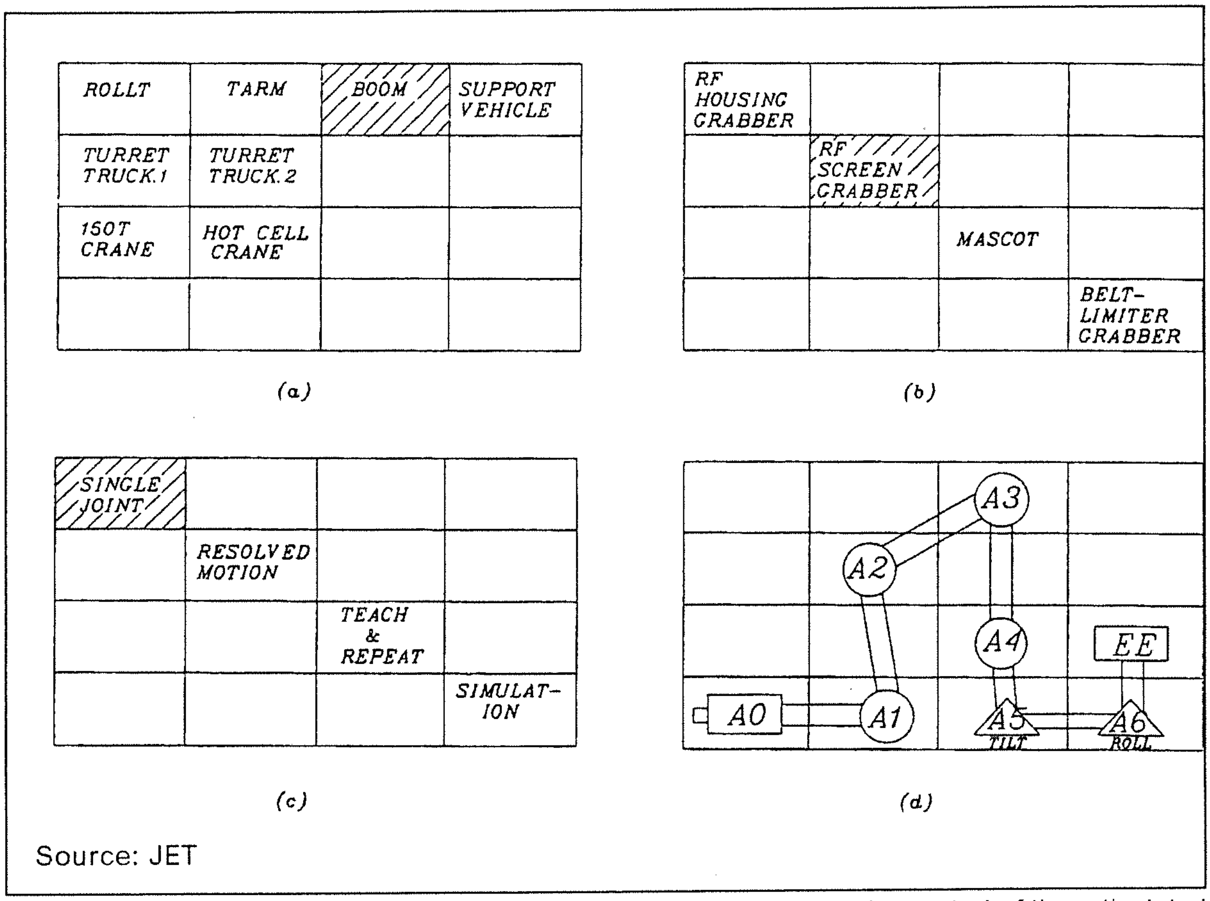


Figure 4. Menu sequence on touch panel. Successive TP pages for the control of the articulated boom.

2.2.3 Remote Handling Workstation Software Architecture

Figure 7 on page 13 shows the software architecture of the RHWS. The operation of the RHWS is based on the NORD-100 RH computer and special Crate Auxiliary Controllers (CAC) in the RHWS. For the control and monitoring of each RH equipment there is an RT-program which runs on the NORD-100 RH computer and configures the RHWS accordingly (attaching input devices to local controllers) using standard JET software (e.g. MIMIC software for generating graphics).The communication software for the serial links runs on the CACs, so that commands from the input devices of the RHWS are transmitted directly to the appropriate RH equipment local controller within the required transmission time.

2.2.4 Process Interface

The process interface of the JRWS consists of three different types:

1. Serial Fiber Link (LWL)
2. CAMAC-Link
3. ETHERNET

This variety is due to the history of the RH development and decisions of non-RH areas, especially data processing for experiments.

For the protocols no standard exists.

```
ROLLT (Roemotly Operatable Low Level Transporter
 | VEHICLE_CONTROL #MP_YAW_ROTATION #MP_PITCH #MP_RAISE/LOWER
 |                 #MP_EXT/RETRACT  #CRANE_RAISE/LOWER
 |                 #BEAM_F/R @MOTION(L/R/F/R)
 | CAMERA_PICTURE_CONTROL
TARM
BOOM
 | RF_HOUSING_GRABBER
 | RF_SCREEN_GRABBER
 |  | SINGLE_JOINT    #A0#A1#A2#A3#A4#A5#A6#EE@MOTION
 |  | RESOLVED_MOTION #A0#A1#A2#A3#A4#A5#A6#EE@MOTION(X/Y/Z)
 | Coordinate_System_Definition
 |  | TEACH&REPEAT
 |  | SIMULATION
 | MASCOT
 | BELT_LIMITER_GRABBER
TURRET_TRUCK_1
TURRET_TRUCK_2
RADIO_CONTROLLED_SUPPORT_VEHICLE
 | VEHICLE_CONTROL     #L/R-BRAKES#LIGHTS#MICROPHON/DATA@MOTION
 | MANIPULATOR CONTROL #GRIPPER#LIGHTS#MICROPHON/DATA@MOTION
 | CAMERA_PICTURE_ALLOCATION
CRANE_150t
 | MAINS_MODE
 |  | CRANE_CONTROL #SPEED_SETTING#MAIN_AUX_HOIST#PRETENSION
 |  |               #LOAD#LIMIT_OVERR#INCHING/NORMAL
 |  |               @MOTION(WEST/EAST/NORTH/SOUTH/RAISE/LOWER)
 |  | CAB_CONTROL   @MOTION(LEFT/RIGHT/UP/DOWN/ROT)
 |  | CAMERA_PICTURE_ALLOCATION
 | BATTERY_MODE
CRANE_HOT_CELL
JC_1...3

            Resulting allocations:    # ---> rocker switch
                                      @ ---> joystick
```

Figure 5. RHWS commands. Basic command tree overview

Comment

The general strategy of using a general purpose remote handling workstation is favoured by KfK too and proposed for NET as well, the functionality should be enhanced, the implementation (hardware components, software architecture, interfaces) has evolved in the specific JET environment and has to be redesigned.

2.3 Graphics Workstation (GWS)

The Graphics Workstation (GWS) is basically used as a monitoring attachment to the JRWS. The GWS provides three-dimensional views of the RH scene based on a geometric model of the RH equipment and the working environment. The model is continuously updated by sensor signals from the RH equipment (e.g. local boom control and MSM control) via an ETHERNET link. The GWS especially provides views in critical areas of work where camera views are limited. The facilities available to view scenes from any vantage point and without the inherent real problems of lighting gives the operator additional significant information and more confidence in controlling.

```
CAMERA_PICTURE_CONTROL
 | TORUS_HALL
 | HOT_CELL
 | IVIS
 | CONTROLLED_EQUIPMENT_CAMERAS
 | OTHER_EQUIPMENT_CAMERAS
 | | ROLLT       #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS
 | | TARM        #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS
 | | BOOM        #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS
 | | TT_1        #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS
 | | TT_2        #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS
 | | CRANE_150t  #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS
 | | CRANE_HC    #PAN#TILT#ROLL#FOCUS#IRIS#ZOOM#LIGHTS

          Resulting allocations:    # ---> rocker switch
                                    @ ---> joystick
```

Figure 6. RHWS command overview. Camera Picture Control Partition

The GWS is used in off-line mode for operator training. In times where the real boom is not available for the operator it is possible to feed the LBC signals into the GWS to get a simulated boom movement.

In addition to this usage of the GWS as training means, the GWS may also be used for planning and programming purposes. In off-line mode the operator can try out a new path for the boom and this path may be downloaded to the LBC for execution. This kind of usage is still in the experimental phase. For planning studies the GWS simulation is being used.

A special application of the GWS, which was not preplanned, was commissioning and installation support especially by showing and logging of motion paths.

Comment

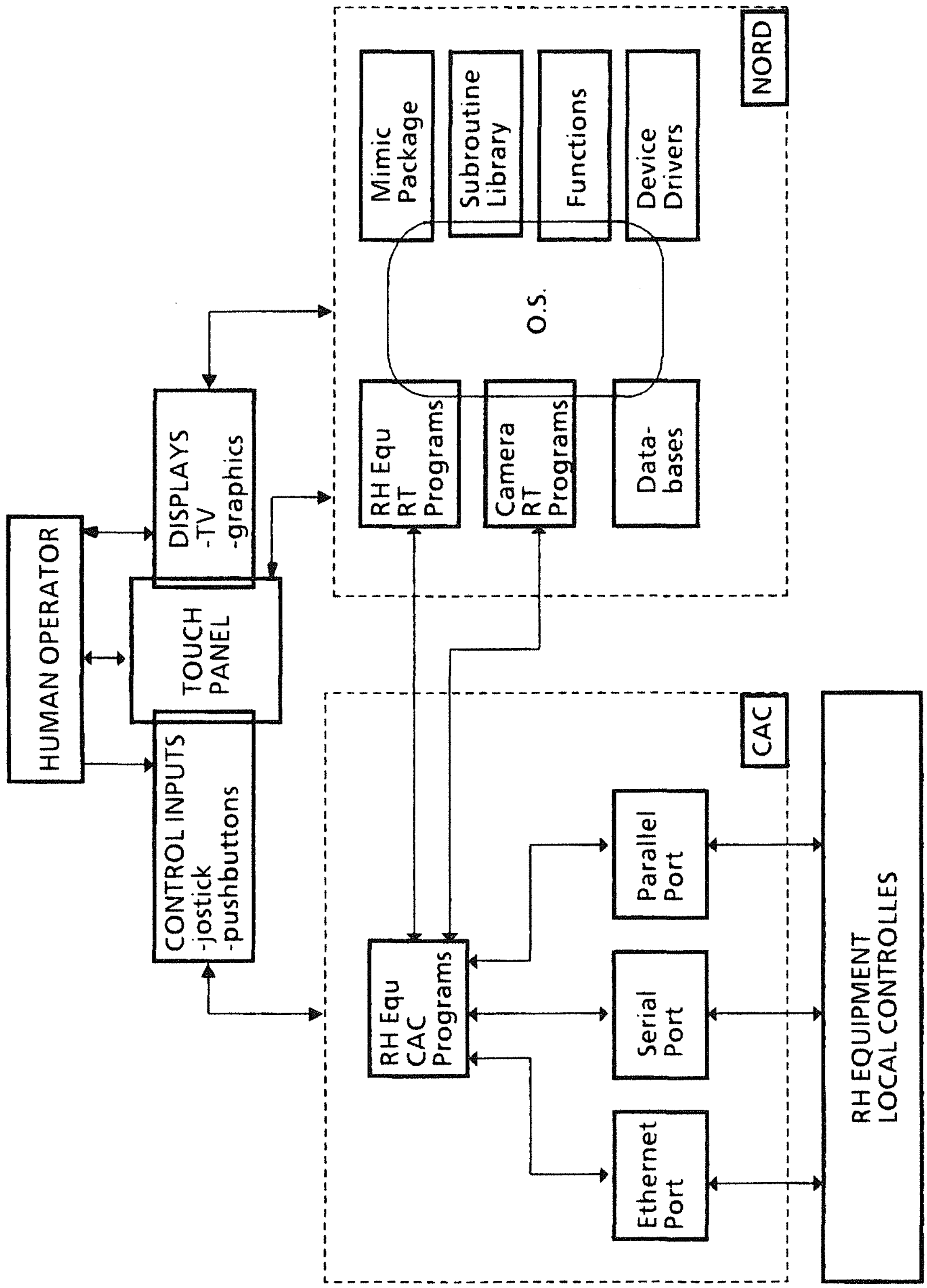
The GWS should not be seen as an appendix to the control system but as an essential, integral part of it. In that case graphics could be used for supporting various subtasks the operator has to do. In the NRWS proposal a graphics simulator will be a main component of the remote handling workstation.

2.4 Servo-Manipulator Master Station

There are two Servo-Manipulator Master Stations (SMMSs) in the control room as shown in Figure 2 on page 8. A SMMS supports the control of the Bi-lateral Mascot including its advanced robotics functions (teach/repeat), the cameras associated with the RH task, the RH tools and the transporter on which the MSM is deployed. The operational work is done by two operators: the manipulator operator (Manop) and the one operator for cameras and general duties (Camop).

Comment

This division of labour between two operators is recommended for NET as well, especially because the functionality (support functions) of the remote handling workstation will be enhanced. This division of labor seems to be natural because the skills needed for the whole tasks are very different: (1) usage of computerized support tools, (2) manual motion control.



Source: JET

Figure 7. Remote Handling Workstation Software Architecture

The SMMS (Figure 8 on page 15) consists of:

- Mascot master station with PC type console,
- 2 fixed 20″ monitors in front of the operator,

- foot switches for special tools and msm brakes,
- 2 movable 20″ monitors mounted on a curved track,
- 1 Remote Handling Workstation,
- 1 Graphic Workstation.

According to the work phase the position of the TV screens may be positioned freely on a sphere sector. The operator is sitting on a special chair, has foot pedals and the master arms.

2.5 Supervisor Station

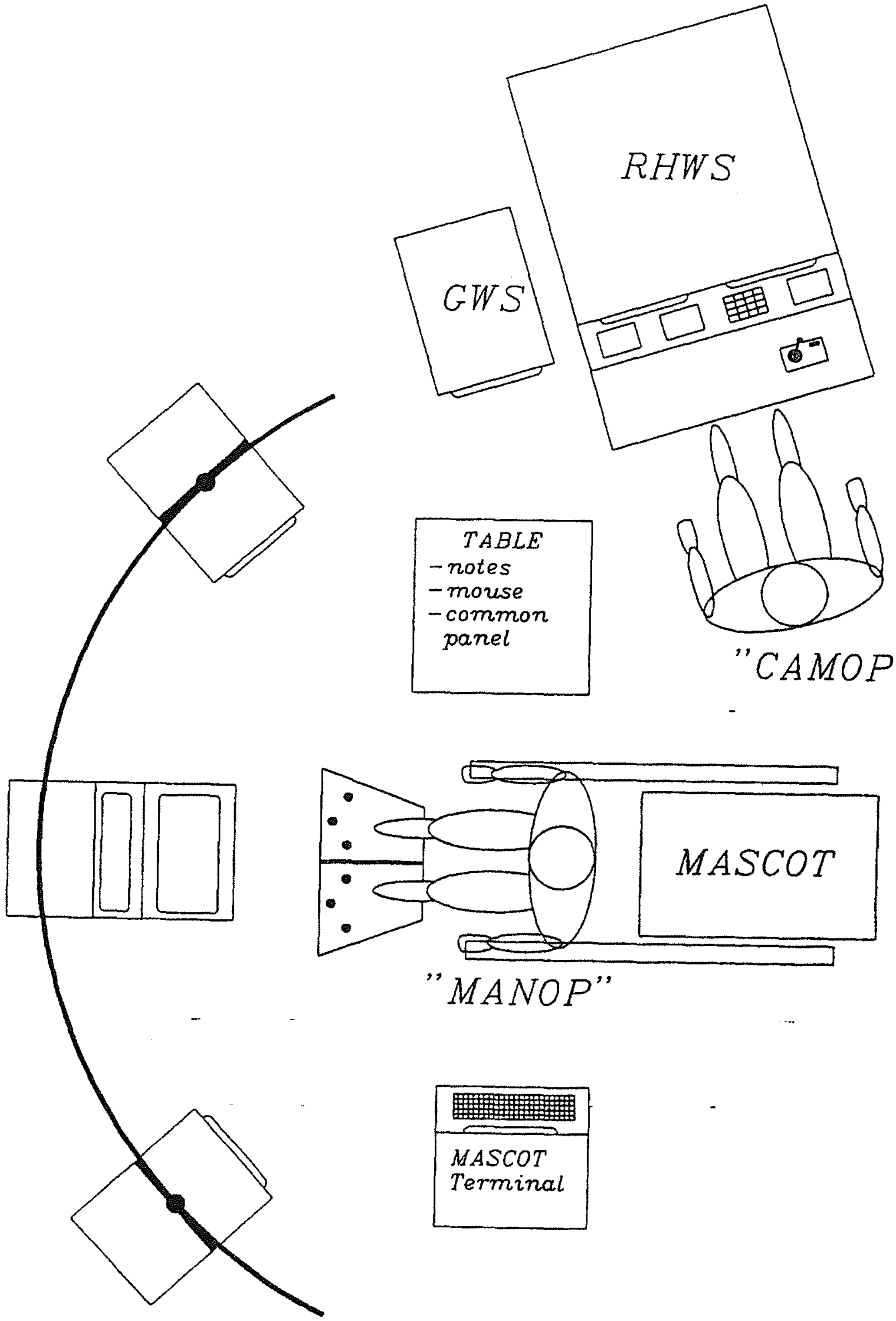
Until now it is not decided whether a supervisory workstation will be provided. The function of a supervisory workstation and the special functions of the supervisor are still in discussion.

Comment

The specific tasks of the NET RH control room supervisor will be proposed in the NRWS proposal.

2.6 Video-Recorders

For logging of work sequences U-matic video recorders are used which are fed through the TV crossbar matrix.



Source: JET

Figure 8. Servo Manipulator Master Station. Layout

3.0 JET TV System

The surveillance of remote maintenance work is based on colour TV feedback information complemented by real time 3D graphics (GWS). The TV signals of approximately 60 TV cameras is fed into a video/audio crossbar matrix so that any camera signal could be connected to the TV screens in the control room (SMMS, RHWS) or into video recorders. Each TV camera is equiped with a microphone, most of them with a light spot. The operator controls the viewing equipment via the RHWS. Figure 9 on page 18 lists the camera locations, the number of cameras at each location, the camera accessories, and the control possibilities. Figure 10 on page 19 shows the architecture of the viewing equipment including the graphics workstations for artificial viewing.

For the future an integration of graphics and camera viewing is planned by implementing a graphics (GWS) based camera control ("Remote Handling Viewing System" or "Integrated Viewing" in the KfK proposals) [4].

Comment

Integrated viewing that means the combination of TV viewing and synthetic viewing (graphics) should be a central subsystem of the NRWS.

Figure 9. Remote Handling Viewing System Definition

Camera Locations	No of Camera Signals	No of Microphone Signals	No of Spotlights	Camera/lens control		Camera Position Feedback	Comments
				Pan/tilt/zoom	Focus/Iris		
Torus Hall	16	16	16	Yes	Yes	Yes	Fixed camera locations. Total of 15 camera units for full RH coverage.
Hot Cell	6	6	6	Yes	Yes	Yes	
Access Cell	6	6	6	Yes	Yes	Yes	
Crane	2	2	2	Yes	Yes	Yes	No RH brackets required.
In-vessel Inspection System	4	0	0	No	No	No	Stand alone special system with video o/p through crossbar.
Articulated Boom	5	5	0	No	No	No	RH mobile equipment with dedicated LCU's for equipment and camera control.
Telescopic Arm	8	8	0	No	No	No	
Low Level Transporter	4	4	0	No	No	No	
Support Vehicle	3	3	0	No	No	No	Video o/p through crossbar
Turret Truck	3	3	0	No	No	No	

Source: JET

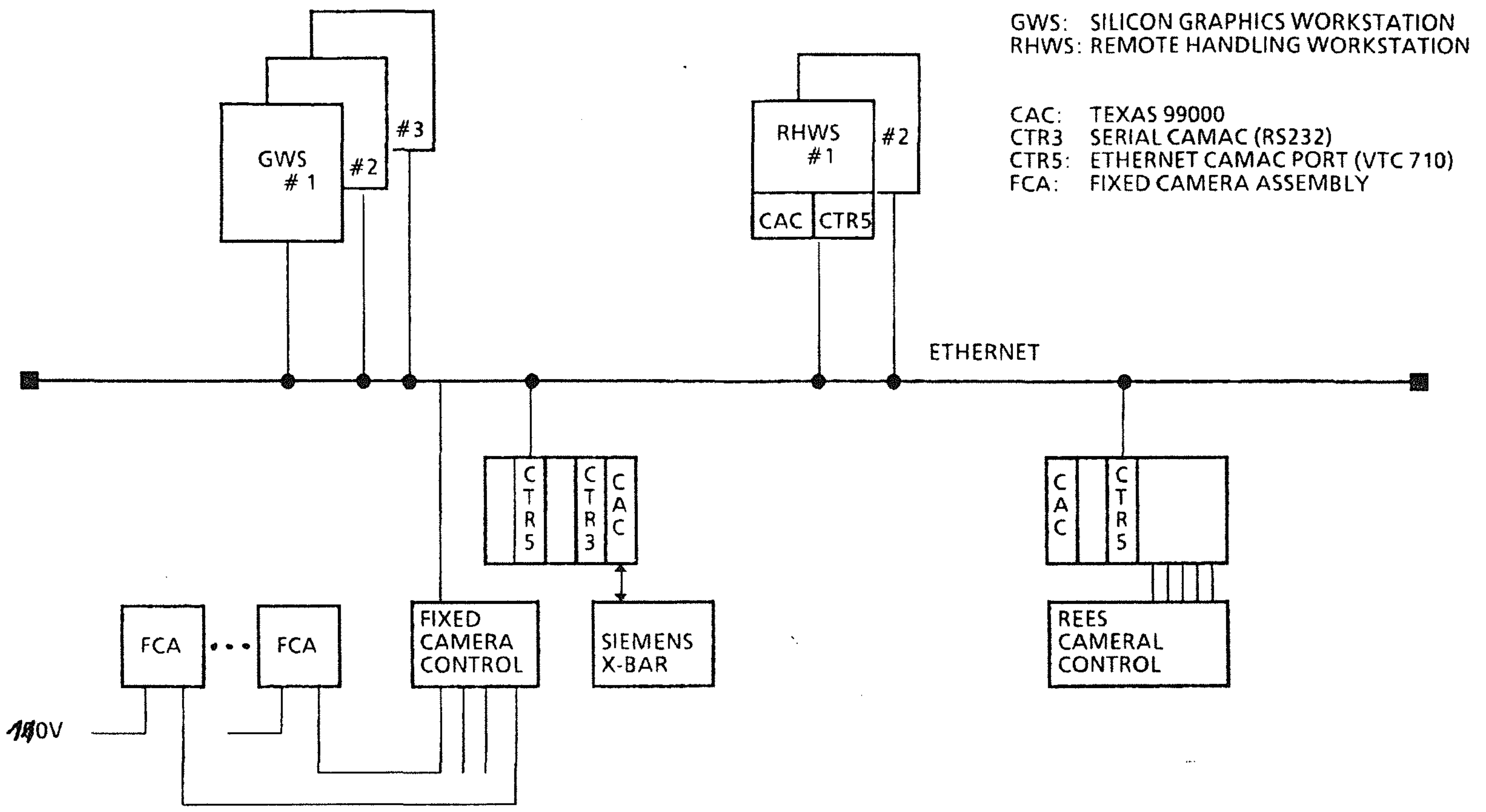


Figure 10. JET Remote Handling Viewing System Architecture

4.0 JET IVIS System

For the inspection of the inner torus wall the In-Vessel Inspection System (IVIS) was developed providing four telescopes for looking into the torus, under vacuum. The telescopic cameras are controlled by a special camera control system newly based on the GBsim graphics to make the control more operator friendly. Besides the integration of graphics the operator is supported by slides archive which is also controlled by computer.

Comment

This is a further example of integrating camera viewing and TV viewing calling for a flexible integration of TV and graphics in the NRWS. The second important aspect of this IVIS control system is the demonstration of the usefulness of a multi-media workstation. The NRWS should at least be prepared for integration of multi-media means e.g. for operator guidance/advice and operator training. As shown at actual engineering workstation exhibitions multi-media support using CD-ROM memories is a developing approach.

5.0 Control System

As a base for the description of the control system concept at JET the TARM control system is used because it is the latest JET development (Figure 11 on page 24).

The overall control system distinguishes three levels of control each of which is equiped with one/several special purpose computers and operating systems. Each control system level is dedicated to a specific class of subtasks of controlling the TARM system

1. Workstation (RHWS/GWS)
2. High Level Control (HLC)
3. Low Level Control (LLC)

The workstation level of control is not considered as a part of the proper control system and was therefore discussed separately in: (2.0, "Remote Handling Workstation and its Environment" on page 7).

5.1 High Level Control

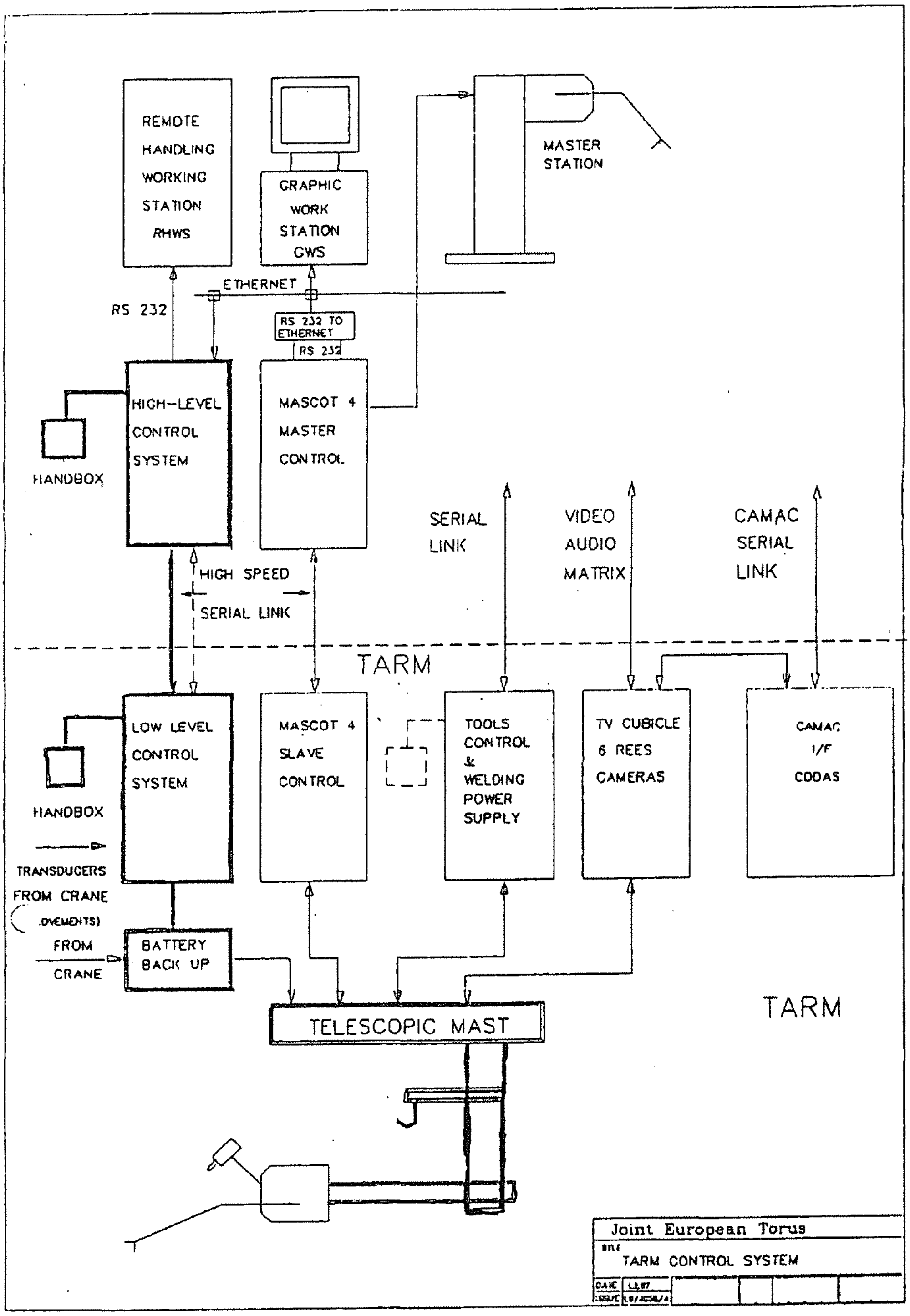
The high level control is only defined for the TARM control system not for all the other control systems. The TARM HLCS is implemented on a DEC-VAX running the VMS operating system and a C compiler. The functions implemented on this HLCS are:

- Command validation and arbitration for controlling all TARM equipment directly or indirectly
- Teach & repeat (including a local library)
- System's command interfacing for handbox, RHWS, GWS
- data collection and processing associated with the LLCS
  - position of TARM, crane, and camera arm
  - velocity of all axis
  - hook positions and loads
  - status of TARM equipment (e.g. brakes,lights, load cells)
  - fault condition information
- Camera tracking (planned)

The complete command set (functionality) available for the RHWS and GWS is found in Appendix C, "TARM Control System Command List" on page 137.

The TARM HLCS takes over functions which are implemented in the older boom control system on the Nord-100 or the Local Boom Controller, to make the control system more flexible, maintainable, adaptable, extensible.

The HLCS has two Ethernet links, one to the GWS (using TCP/IP protocol) and one to the LLCS (using ISO/OSI protocol software iNA960). The links to the NRWS and the handbox (a personal computer based system) serial links providing the same functionality as the GWS-Ethernet link.



Source: JET

Figure 11. Architecture of TARM Control System

5.2 Low Level Control

The local controllers or LLCS except the TARM LLCS are mostly based on PCs. The number of local control units is at about 15. The LLCS of the TARM system is based on SMP/AMS-cards using the 8086 microprocessor.

All local controllers have their one MMI especially for tests and commissioning. All functions are available for the super-ordinated control system level (e.g. workstation, TARM high level control)

The TARM LLCS functions are:

- Functional tests
- Closed loop servo-control of all motions, with programmable PID gains and other constants
- Open loop velocity control of J4-joint motions
- Operational monitoring functions for
  - status circuits
  - sensor data consistency
  - uncontrolled motion
  - software position limit
  - limits
  - etc.
- Low level command interface
- Kinematic functions to translate PoR motion commands into appropriate set point for axis servos

During execution of taught-in procedures the operator may be provided with advice requesting execution of manual subtasks. This textual advice has to be programmed during the teaching process as operator messages.

Comment

The basic structure of the control system is in accordance with the KfK NET proposal (hierarchical architecture).

6.0 Communication System

The backbone of the so-called Remote Handling Integrated Control System (RHICS) is a communication system which is shown in its relation to the JET buildings in Figure 12 on page 28. The communication system connects the various RH control system components in the various rooms to form the RHICS. The planned functional status of the RHICS communication facilities is shown in Figure 13 on page 29. Figure 14 on page 30 especially points out the integration of the GWS into the RHICS.

6.1 Architecture

The backbone of the communication system is the CAMAC serial highway (5 MBit serial). The speed of this channel is reduced by the NORD-100 computer which manages the message transfer in the RH control system. Therefore, because the system can not guarantee response times < =250 ms, it is not usable for real-time message transmission. Thus dedicated serial links have been provided for message transmission to the local control units (LCUs). RS232 standardized links are used running at 19.2 KBaud, with a link layer protocol defined by JET. The communication software runs on Crate Auxiliary Controllers (CACs) based on the TMS99000. Data gathering for the GWS and parts of camera control are done via an ETHERNET network run by the TCP/IP protocol. The raw data load on this channel is about 70 kBaud.

Comment

The architecture of the communication system is not the result of a design study but it is due to a historical growth process. The basic decision was to use the available CAMAC highway for RH too. The other communication channels where implemented later on to overcome the communication problems which appeared in using a link, designed for data acquisition and control in an application with special response time restrictions (< =250 ms).

A main problem in establishing the RHICS was the communications problem (the cabling). A thorough analysis and design of this basic subsystem is highly recommended for future work [4] [3].

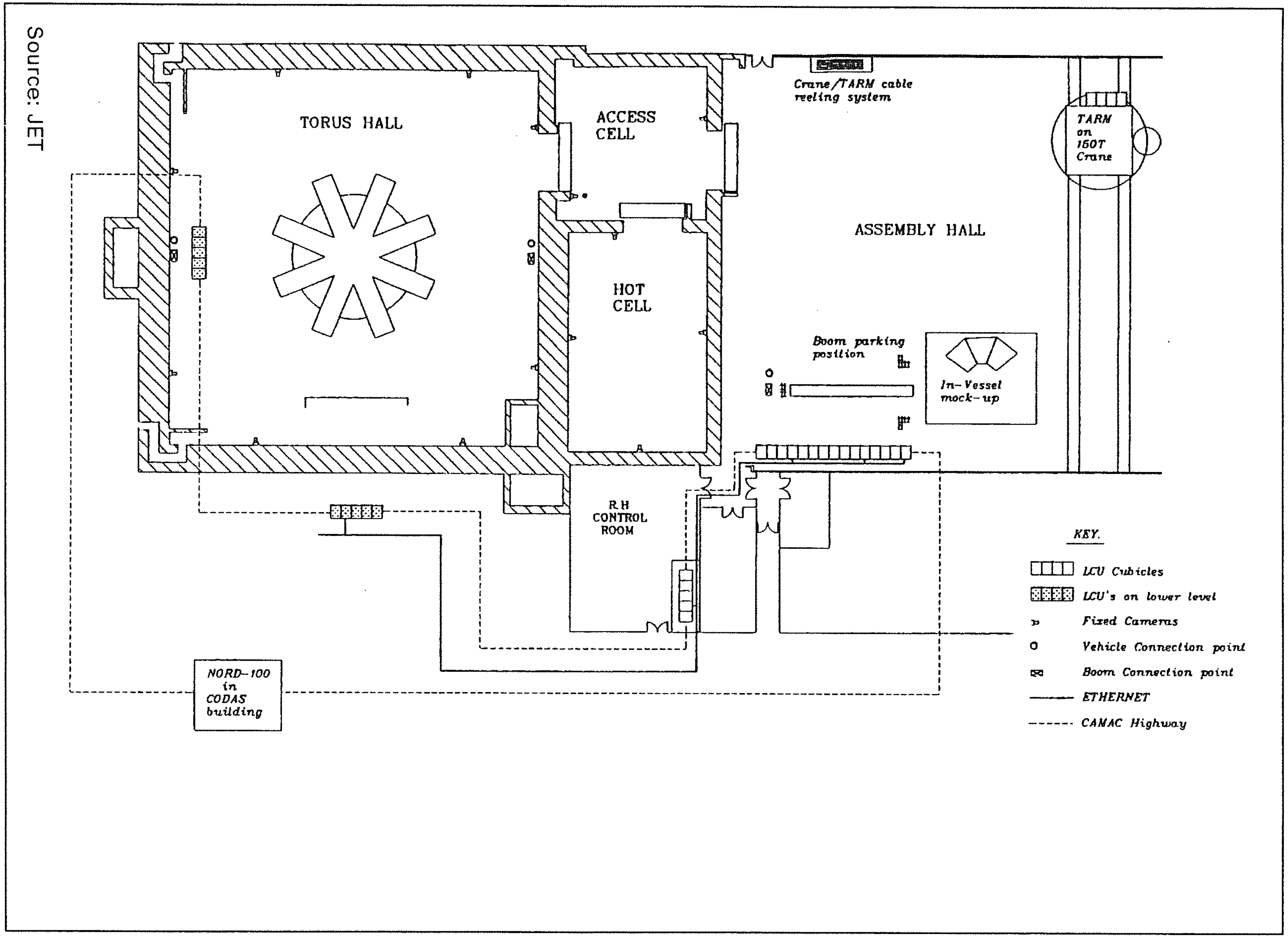
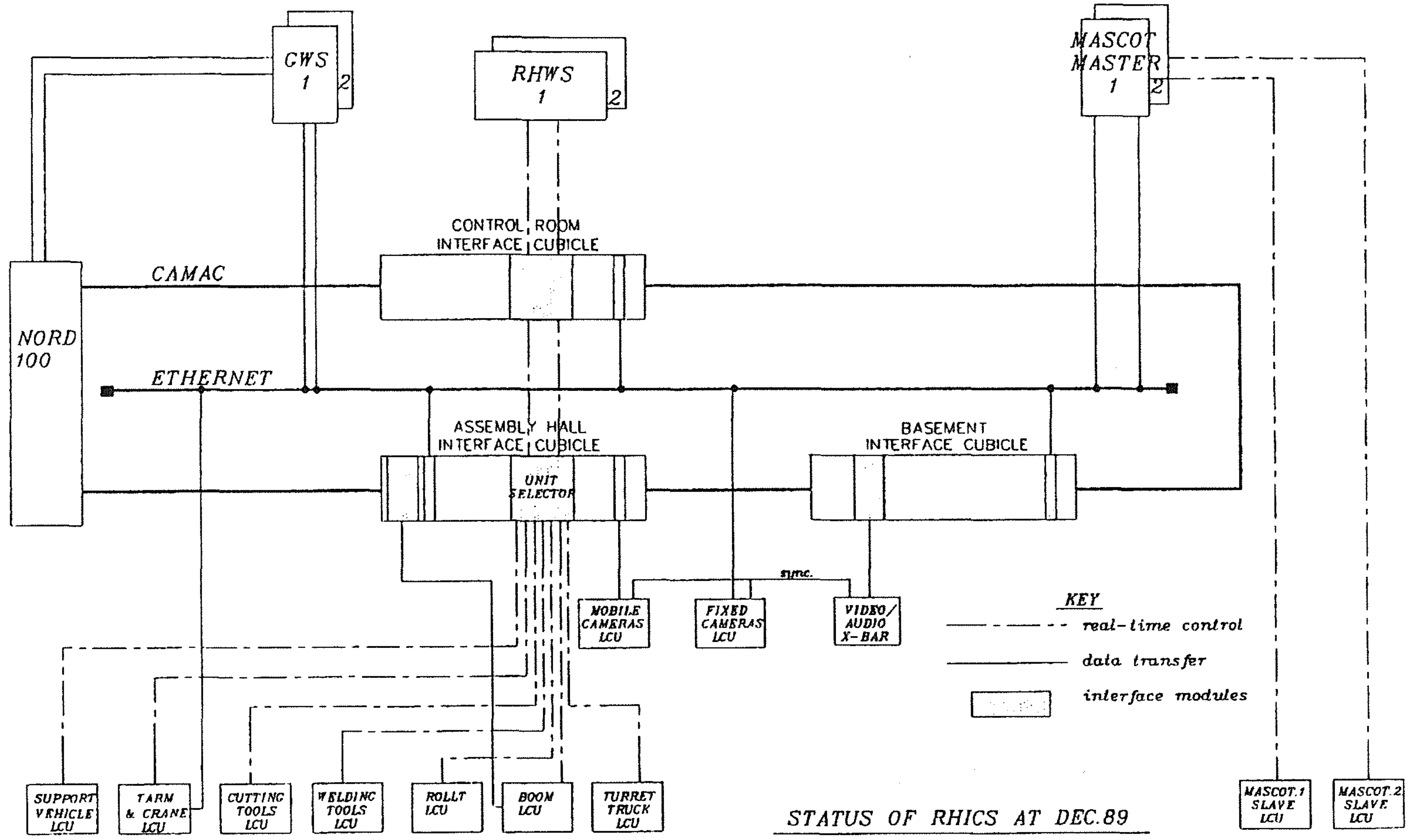
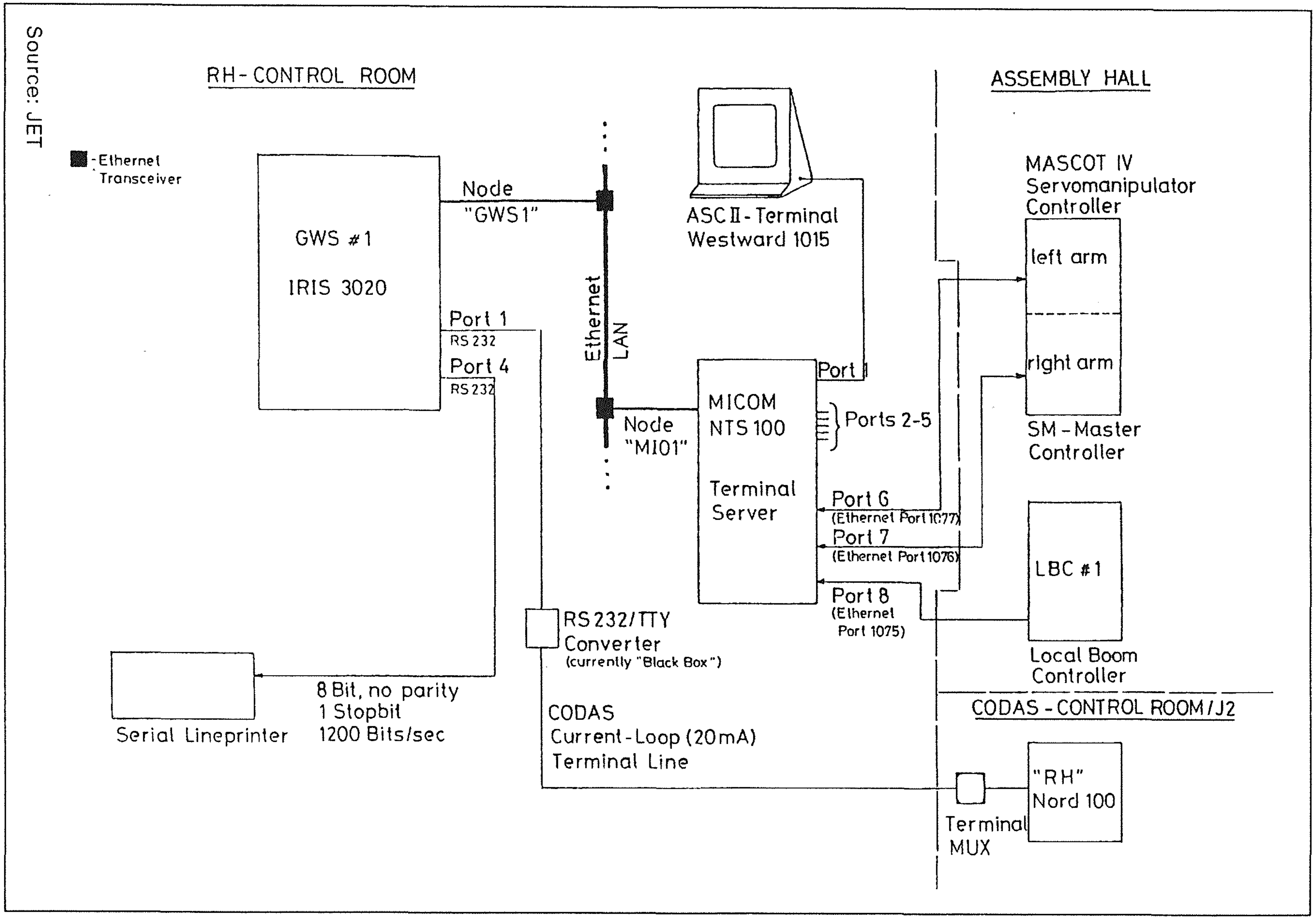


Figure 12. Overall RHICS equipment layout in JET building



Source: JET

Figure 13. Status of RHICS at Dec.89



Source: JET

Figure 14. RHICS detail: GWS Integration

7.0 Auxiliaries

7.1 CAD System

To support the generation and management of the geometric model for the GWS the CAD system IBM-CATIA is used. The data will be transformed to the GWS format by a special processing software provided by KfK in conjunction with the GWS software.

7.2 General RH Data Bases

For the planning phase JET has established two databases the RH procedure database which contains all information about the preplanned RH procedures and the RH equipment database which contains data about the complete RH equipment.

7.3 RH Procedure Database

The designer of any equipment to be attached to the machine must make sure of remote handling compatibility. For all components which have to be handled remotely for maintenance purposes a remote handling procedure has to be worked out. These procedures contain informations about

- preparational work, needed state of the machine
- needed RH equipment and tools,
- site requirements,
- additional information about special geometric restrictions mostly in form of drawings,
- general description of the procedure and boundary conditions,
- detailed description of the procedure in form of elementary steps or standard (common) procedures which are described in detail elsewhere.

An example of such a procedure description is contained in the enclosed material: Fogg, P.A.: A1 Antenna Screen Installation.

Based on this documents the time dependence of the procedures is investigated using a standard PC based project management system. On the base of the stepwise description of the procedure, the time needed for a single step, and the availability of needed resources the system computes the total duration of the procedure and a summary of the resource allocation over the time. An example of a result of the computer based procedure planning is contained in the enclosed material: GANTT CHART for Screen replacement.

If RH tasks do not proceed as planned in the procedures then an analysis of the problem will be made by in-situ inspection and comparison to video recordings of the task mock-up previously made. The solution of the problem will then be tried and tested using spare equipment in the mock-up areas [8].

7.4 RH Equipment Database

The basic resources for execution of RH procedures are the remote handling equipment and tools. As a first approach for resource management JET has established a RH database using a PC based bill-of-material system called CIMTEL. This database is hierarchically structures and contains all relevant information about RH equipment and tools. This database is used for planning RH procedures and for maintenance of the remote handling equipment.

Comment

There are a group of RH subsystems which are used on the operator support or tasking level of the control system and which therefore should be seen as components of an Advanced Remote Handling Workstation or which should be accessible from such a workstation:

1. Remote Handling Workstation (RHWS)
2. Graphic Workstation (GWS)
3. RH procedure database
4. RH equipment database

7.5 Computers

The centralized RH computer (NORD-100) is mainly used as an extension of the RHWS, to give the RHWS computing power. It has to be seen as an integral component of the RHWS which itself has only limited computing power used especially for input bypassing functions.

Another function of the RH-computer is to serve a data base for taught-in (learned) motion programs for the RH-equipment (e.g. boom control programs).

The NORD-100 computer and the basic CAMAC equipment of JET are supplemented by a group of various types of computers used for special control purposes:

- microVAX for TARM-HLCS
- AMS/SMP-8086/87 microprocessors for TARM-LLCS
- SPS-(memory programmable controller)-hardware for boom control system
- PC based systems especially for Local Control Units controlling limited degrees of freedom

Comment

The implementation of a RH workstation should not be based on a central computer. For the NRWS so-called workstations should be used, such that a NRWS is composed of several special purpose workstations which will be integrated to the NRWS by a state-of-the-art communication concept.

Section 2. State of the Art: Workstations in general

8.0 Introduction

The JET Remote Handling Workstation is the basic reference system for a NRWS. But in addition to the JET state-of-the-art report Section 1, "State of the Art: JET Workstation" on page 1 this report reviews shortly workstations and workstation development trends in related application areas. Of coarse, the design of an operator workstation depends on the kind of application, but basic concepts in workstation architecture and functionality should be transferable because the basic tasks of operator support in controlling complex systems is the same. Especially the successful introduction of computers on the operating or task level of the control system for JET remote maintenance lets expect additional intelligent support for the operator as known from related applications.

The general direction of the development in operators workstations in all application areas is to support the operator not only in providing a good information display, but to support him in his basic tasks and to put him stepwise more and more in the role of a planner and supervisor who only has to select automated subfunctions, to bridge gaps in automation, and to intervene in case of malfunction. All papers emphasize the support of the operator by high level mostly interactive tools which are by far not state of the art, but which are under development. This demands for an open architecture of the NRWS.

In all reported work the workstation with its "intelligence" is the basis for the man-machine cooperation and the goal is to enhance this cooperation and the abilities of both partners.

9.0 Application and Development Reports

9.1 General Concepts of Man-Machine Cooperation

Based on investigations on controlling manipulators and vehicles for remote inspection and work in the deep ocean at the MIT a general framework for such a class of work was defined as **Supervisory Control** [12][13] [14]. A supervisory control system organizes and supports the man-machine cooperation. Supervisory control systems are semi-automatic control systems where control is shared between man and computer. Sheridan presents a scheme by which human activities in supervising physical processes are categorized. For each function of the operator doing remote work, the computer will have to play a role in aiding the human operator. The basic functions of the operator are:

1. planning,
2. teaching (giving orders to the computerized system),
3. monitoring,
4. intervening,
5. learning.

The related computer aids for the operator are:

1. physical process training aid, goal setting aids, procedure training and optimization aids, procedure library, action decision aid (in-situ simulation);
2. aid for editing commands;
3. aid for calibration and combination of measures, estimation aid, detection and diagnosis aid for failure or halt;
4. abort execution aid, normal completion execution aid;
5. immediate record and memory logger, cumulative record and analysis.

9.2 Man-Robot Symbiosis

The related work at ORNL [15], [16], [17], [18], [19]has the fundamental objective to bridge the gap between fully autonomous and fully human-controlled systems to achieve full man-robot cooperative control and intelligence. such a cooperative system merges advantages of fully autonomous systems (e.g. efficient repetitive task execution and immunity from fatigue) with those of fully human-controlled systems (e.g. expertise in wide task domains and the ability to cope with unexpected events) to improve the performance of current systems. The ultimate function of the symbiotic system is to dynamically optimize the division of work between the human and the robot to facilitate their cooperation in decision-making and the control of tasks in a complex, dynamic environment. The basic modules of the proposed and partly implemented system are:

- job planner,
- dynamic task allocator,
- presenter/interpreter,
- automated monitor,
- learning system.

First experiment where done with simple but typical remote handling tasks like transferring a wrench from a table to a toolbox.

9.3 *Fuel Reprocessing Plant Maintenance*

The remote maintenance control room layout of a nuclear fuel reprocessing [20]is based on the following steps:

1. function list development,
2. function organization,
3. crew requirements determination and function allocation,
4. conceptual design of control panels,
5. panel integration into workstations, workstation into team, and teams into control room layout.

Each team includes an operator responsible for the manipulation and transporter movement and a support operator responsible for crane motion and television control. The control room will include three two-person teams, one single-person team (crane), and a supervisor. For each team there will be a workstation, the supervisor workstation has a different layout, suited to the collision prevention task. The workstations do not contain enhanced support features.

9.4 *NASA Research and Development for Space Telerobotics*

The general research objective is the fusion of robot sensing and manipulation, teleoperation, and human and machine cognitive skills into an effective architecture for supervised task automation [21]. The first demonstration will be a laboratory demonstration of grappling, docking, and servicing of a satellite taskboard. A typical task sequence may be:

1. find task coordinate frame
2. open thermal blanket, secure
3. acquire power driver
4. loosen captive screws with power driver while holding cover
5. stow power driver
6. remove and stow cover
7. release module retention clamps
8. withdraw and stow module
9. acquire and insert replacement module
10. tighten module retention clamps
11. acquire cover
12. align and hold cover
13. acquire power driver
14. tighten captive screws with power driver
15. test screws

16. stow power driver
17. release, grasp thermal blanket
18. drape blanket
19. fasten blanket
20. inspect

The performance of those tasks is tackled with an basic control system that can logically evolve with future technology advance. The engineering development objective is to first establish a baseline operational capability for teleoperation; later technology upgrades will incorporate automated task sequencing modes into a preexisting telerobotic architectural framework that is a proposed hierarchical control system called NASREM (NASA Standard Reference Model for telerobotic control system architecture) [22] [23]. As basic information for the task allocation problem and task planning in [24] a performance metric for elementary tasks was developed. This work relates to each elementary task (e.g. peg-in-the-hole, turn a crank, remove a bolt, place module into latches) a complexity measure

The basic modules of the overall system in the field of high level control (operator's workstation functionality) are:

- Task planning and reasoning: Logical reasoning and spatial planning of alternative task activity sequences leading to efficient task completion (sequence planning, monitoring and diagnosis, spatial planning, causal modelling, reasoning with uncertainty). The planning system is an interactive system [25].
- Operator interface: Human factors considerations and display/control interface requirements enabling smooth and efficient transition of control between operator and machine; usage of graphics and stereo TV. The graphics interface provides windows to look into models used by the interactive task planner. Through this graphics interface task planning and execution can be controlled.
- System architecture and integration: computing architecture enabling real-time execution of autonomous functions, system architectures enabling smooth integration of these functions under operator supervisory control (network architectures, task control and complexity analysis, database design and management, system simulation and programming).
- Teleoperation subsystem: functions necessary to control a high-fidelity, dual-arm, six-degree-of-freedom teleoperator with a universal hand controller.

A hierarchical human-machine interface provides a flexible supervisory control, which allows the operator to enter the robot sensing and control hierarchy at any level necessary, for purpose of task planning, monitoring, or direct execution.

In the experimental setup of remote handling the motion controllers are mostly standard robot control systems with VAL II programming language which are subordinated to the operator workstation (HP workstations). Using a layered communication standard as ISO/OSI is helpful for integration of a growing system [26].

In [27] the usability of the different input devices were tested in a docking and tracking experiment. The input devices were integrated in the Advanced Space Cockpit Workstation, which also provides support functions with graphic and touch-sensitive displays: docking and tracking reticles are superimposed on the related TV images from the end-effector camera. The experiments shows only minor differences between a 6-DOF and 3-DOF input device. A hand-controller technology overview is given in [28]with respect to

1. hand-grip design,
2. control input devices, and

3. control strategies.

14 hand-grip designs are reviewed and evaluated in the light of human factor considerations. 12 input devices were

- evaluated in terms of
- task performance,
- configuration and force
- feedback,
- controller/slave correspondence,
- operating volume,
- operator workload,
- human limitations,
- cross coupling,
- singularities,
- anthropomorphic characteristics,
- physical complexity,
- control/display
- interference,
- accuracy,
- technological base,
- cost, and
- reliability.

9.5 *Telerobotics with Master-Slave Manipulator*

As reported in [29] and [30] at CEA good results were achieved performing telerobotic tasks with a master-slave system integrated into a supervisory control system. The operator may work as a planner, supervisor or executor. The supporting tools which are or will be available for him at the workstation are:

- task planning system,
- control sharing between system and operator,
- decision support system,
- graphic scene presentation, graphic indicators,
- stereo TV (with spectacles), standard TV
- standard 6 DOF master arm, universal force reflecting mini master arm

9.6 *Telerobotic Maintenance of Power Lines*

At the high level of the control system for maintenance of power lines the operator will have available [31]:

- Unified user interface, facilitating the integration of robotic and teleoperator modes, and a uniform front-end for the various knowledge-based modules;
- Tools for aiding in planning, programming, and monitoring task execution;
- Tools for error handling (detection, analysis, and recovery);
- Tools for advising (in the simplest case by texts provided by the human task programmer).

The implementational basis for the telerobotics workstation are some SUN workstations.

9.7 *Inspection of Offshore Platforms*

Basic operator supports in a supervisory control system for offshore platform inspections [34]:

1. motion planning support,

2. execution monitoring,

3. manual intervention with computer controlled geometric constraints to manual manipulator control.

9.8 *Workstations for Ship Machine Control*

As an central components in an operator's workstation for controlling a ship's drive in [45] are proposed, based on simulation experiments: (1) a meaningful information display using computer graphics based on information preprocessing and (2) a knowledge based fault diagnosis system.

9.9 *Flexible Manufacturing*

The supervisor of a flexible manufacturing system has to do tasks comparable to the maintenance supervisor. Both have to guarantee the exact performance of plans and schedules. For the supervisor in manufacturing plants [33] proposes a workstation, through which the operator can monitor the process, tune the parameters, and effectively compensate for the deficiencies of the current performance. This calls for special tools for state presentation of the manufacturing (maintenance) process and for special monitoring and replanning tools.

9.10 *Man-Machine Interface for Supervisory Workstations*

As pointed out in [32], traditionally, control rooms and operator workstations are defined at a very complex level of representation. Display information is hardware oriented and depends on the one-sensor/one-indicator technology. Thus the operator are confronted with a large number of electro-mechanical displays and computer-based display pages. In such workstations, for example in satellite control, only one level of information is available, the most detailed, which does not support operator's decision making. As an effective design alternative model-based workstations using a model of the operator function and representing the system by means of qualitative icons and dynamic.windows is proposed and tested successfully for NASA tasks. Such an interface is dynamic, adapting to the current operator function. This type of workstation is likely to have high visual momentum and facilitate rapid transition from passive monitoring functions to active fault detection, identification, and compensation functions. Experiences were gained with supervisory control systems where decision making is in real-time and where low-level operations are primarily automatic. The interface design is so important because the complexity of the interface determines, for the operator, the complexity of the system, and the effectiveness of a supervisory system depends on the means for coping with the complexity of the system.

9.11 Workstations as Information Processor

In supervisory or semi-automatic control systems the operator efforts are shifted to coordinating lower level subtasks and towards decision making and problem solving. This demands for an environment for storing, generating, and manipulating information. This means that workplaces will take on the form of workstations, a subsystem with access to information of several sources and related information processing to assist the operator in his information processing task. This is for example done by displaying the information in different levels of abstraction suited to the current needs [35]. General guidelines for man-machine interface design in the light of the special human abilities are discussed in [36]and [37].

For the implementation of a flexible and high performance man-machine interface the dialogue and presentation task is separated from the application and defined as a general task. To support the implementation of this subtask the user interface management systems (UIMS) were defined as an implementation and unification aid for user interfaces [38], [39], [40]. The basis for UIMSs are so-called window systems which determine the final appearance of the man-machine interface. A quasi standard in this area is the X window system developed at MIT [41]. The main features of this window system are:

- workstation independent
- support of different application and management interfaces
- network transparent
- support of multiple applications concurrently
- support of overlapping windows, including output to partially obscured windows
- support of a hierarchy of resizable windows, and an application can use many windows at once
- support of high quality and high performance texts and graphics
- extendability

A broad survey of human-computer interface work is given in [42] covering: dialogue independence, structural modelling, representation, interactive tools, rapid prototyping, development methodologies, and control structures. The structure of a dialogue transaction model is presented in [43].

9.12 Nuclear Power Stations

A good overview over the trends of man-machine interfacing in nuclear power stations is given in [50]. The papers show, that recent development of computer technologies, and also of information processing, e.g. artificial intelligence, offers great potential to design future control rooms for nuclear power plants with enhanced information processing capabilities. The general attitude to the use of computers in nuclear power plants is positive with some exceptions in particular areas. The application areas of data gathering, information display, data logging, and operator aids are considered appropriate. Among others, research needs in the area of human-computer interface techniques is given high priority. Main topics of the conference were:

- Human behaviour in plant operation
- plant personnel training,
- operator support,
- Artificial intelligence and accident management,

- Process control and human engineering in control rooms,
- Robots for nuclear power plant inspection and maintenance,
- Human engineering in controls and control rooms,
- Transients and accident management,
- Robotics.

The EPRI-Institution has developed the PLEXSYS [57]system to aid process and nuclear power plant engineers in producing knowledge bases of hydraulic, electrical, and information systems which may be used to support the plant maintenance and plant monitoring.

9.13 Advanced Operator Guidance

To provide control advices for the operator of a iron ore sinter plant expert system techniques are used successfully [46]. Issues encountered in building the system to the on-line test stage are discussed and some advices offered to new expert system developers.

Some basic ideas of bringing planning advices at a cognitively appropriate level for the user are discussed in [44].

In [48],[49], [47]research on the topics interface modularity, adaptability to the individual user, direct support of the user intentions, and an intelligent advising capability is reported.

9.14 General

General aspects but also specific applications are found in[51], [52], [53], and [54]. The focus in all three papers is man-machine interaction and operator support. The trends in these fields are to use UNIX workstations with window techniques and knowledge based tools for operator support in planning and troubleshooting or adaption of the man-computer dialogue to the actual situation ("intelligent support", "intelligent interface"). Of special interest in various application is multi-media information presentation: combination of TV and computer graphics, input via touch screen, mouse, and speech.

In [55] a prototypic implementation (ProMiSe: Process Control & Monitoring System) is described which realizes a application independent user interface to a process control system. The system uses a UNIX/MS-DOS environment, UNIX/UNIX and UNIX/VMS are planned. As very user interface the system THESEUS is used.

In [56] network models are proposed as a basis for operator guidance systems in process control.

9.15 TELEMAN

TELEMAN is a four year program of the European Commission [58]dedicated to remote handling in hazardous or disordered nuclear environments. The objective of the program is to develop advanced teleoperators which will reduce present man-dose levels, improve productivity and enable public authorities to deal more effectively with nuclear accidents. For TELEMAN computer assisted tele-operators must function in manual (e.g. master-slave) control modes and preprogrammed or autonomous modes under operator supervision. Autonomy implies artificial intelligence, the ability to integrate inputs from different sensors in a goal driven manner, and safe automatic accomodation of system deficiencies and failures. Other important control issues are management system with redundant degrees of freedom, selective presentation of information to the operator, workstation ergonomics, control architectures for multi-robot working. In a pre-study performed by Harwell Laboratory [58] a basic framework for developments was evaluated concerning control system architecture and communications. As a basic reference architecture for a telerobotic control system the NASA NASREM architecture taken. The standard modules and interfaces defined in this model aid the entire software development cycle and facilitate the integration of telerobotic components (software and hardware) from a variety of sources. The model is hierarchically structured into six levels:

1. Translation motion data from a general coordinate frame into joint coordinates and senses joint positions, velocities, and forces.
2. Generation of smooth trajectories in the chosen frame from intermediate positions by calculating the inertial dynamics.
3. Decomposition of elementary moves into intermediate poses taking account of potential collisions and avoiding kinematic singularities.
4. Decomposition of tasks into sequences of elementary moves for the manipulator or vehicle, and scheduling of their coordinated activities (at elementary move level).
5. Decomposition of tasks on groups of objects into tasks performed on individual objects and scheduling of actions of the telerobotic system working in conjunction with other machines.
6. Decomposition of mission in order to assign resources and scheduling of them between work sites and prioritization of activities.

In addition, the architecture is horizontally partitioned into three functions at each level:

1. Task Decomposition performs planning, task monitoring and execution, both temporarily and spatially.
2. World Modelling maintains the global memory, predicts sensory input and resultant future states.
3. Sensory Processing compares observations with predictions and integrates the correlation and difference over space and time to achieve sensor data fusion.

Operator interfaces may exist to all levels with an entire spectrum of control from teleoperation through supervision to fully automatic mode:

Level 1 allows a replica master or set of joysticks to be used to control positions, rate or force.

Level 2 or above gives resolved motion, force or rate control.

Level 3 accepts coordinates of safe motion pathways and computes dynamically efficient movements.

Level 4 permits the use of symbolic definitions for key poses and elementary moves.

Level 5 allows the operator to indicate tasks on objects.

Level 6 gives the possibility to assign telerobots to tasks.

At the highest level the mission operators schedule is defined.

The operator interface may be for real-time control or simply used to modify autonomous plans before they execute. In a supervisory mode assistance may be given to the sensory processing modules, utilizing the interpretative abilities of the operator for image analysis where otherwise sophisticated processing would be necessary. Process synchronization must be within milliseconds at level 1 for a high performance manipulator, increasing by an order of magnitude at each level up to level 6 where synchronization within minutes is sufficient.

For communication the following standards where chosen:

Bus system. VME, MULTIBUS II, STE, IBM PC-AT, Micro Channel Architecture (within the machines); FDDI, FIELDBUS (workplace to machine)

Video. broadcast standard (e.g. PAL)

Inter-workstation communication. ETHERNET with TCP/IP, FDDI

Programming languages. C, C++, ADA, IRL, PROLOG, LISP

Operating systems. UNIX, VMS, MS-DOS, OS/2, iRMX II, OS-9

Software development tool. Any tools or procedures assuring software quality

10.0 Conclusion

Independent of the kind of supervisory work and the level of automation in a human-machine controlled system the following tendency of development is to be seen:

1. State presentation of the controlled system should be done by intelligent software based information processing techniques to assist the operator in state perception and fault diagnosis.

2. Planning (replanning) subsystems (automatic or semi-automatic) should be available to the operator for ad-hoc planning. This includes planning on functional, procedural, and on the spatial domain. As a planning subsystem, simulators have to be available.

3. Even in doing simple manual task the computer is interpreting the human input for failure prevention and help.

4. Especially on the higher levels of control knowledge based systems will be introduced to support the operator. A workstation therefore should be designed at least for later integration of such tools. It should be investigated whether the needed knowledge bases could be implemented at first for operator interpretation.

5. In many cases the supervisory or telerobotics workstations are based on the engineering workstation hardware with standard software and communication interfaces as basic tools (high performance 32 bit processor, UNIX, Ethernet, high resolution screen). This facilitates the integration of different intelligent support subsystems to one supervisory workstation. For advanced operator support special hardware or software enhancements (e.g. for graphics, knowledge based software) are added.

6. In all papers related to telerobotics a general architecture has been evolved which is best represented by the NASREM proposal. NASREM forms the base for the European Community TELEMAN framework and the European Space Agency framework. This framework together with a set of relevant standards as development and implementation environment of the TELEMAN activity should be considered seriously for NET applications.

Section 3. NRWS Alternatives, Trade-off, and Recommendations

11.0 Introduction

The maintenance work at the NET site will be organized into special remote handling areas (RH-areas). These RH-areas are functionally centered around a major maintenance tool like for example the in-vessel handling unit (IVHU). Each RH-area will have its own RH-area control system controlling the central RH unit and its supporting devices (e.g. cameras).

At JET the different control systems have to be attached to one of the general purpose remote handling workstations (JRWS) which provides the man-machine interface of the control system for the operator. Together with the JET remote handling computer the JRWS

- provides standard TV dislays and graphic displays for state presentation;
- allows for attaching control functions (e.g. camera control) to input devices (e.g. function keys, roller ball);
- provides special means for controlling special tools as for example a welding machine (display of selected parameters like welding current).
- As an attachment to the JRWS a graphics workstation (GWS) provides a spatial simulator, used for operator training, planning, and monitoring (real-time three-dimensional graphic scene presentation) including a collision detection subsystem.

A general purpose remote handling workstation is not the only possible solution for provision of a man-machine interface. An important basis for a design decision concerning the characteristics of a NRWS are the following RH control system parameters:

- Number of RH-areas: 5...8 (n)
- Number of simultaneously active RH-area control systems: 2...3 (m)
- Number of control rooms: 1
- Number of RH supervisors: 1

12.0 Alternatives

The JET approach of interfacing the operator with the control system is not the only possible solution. In the following sub-chapters therefore other possibilities are briefly presented to show the basic philosophy behind them. The alternatives to be discussed are:

1. General Purpose Remote Handling Workstation,
2. Special Purpose Remote Handling Workstation,
3. Off-line Remote Handling Workstation.

In this context a REMOTE HANDLING WORKSTATION represents

1. the interface between the operator and the control system and in addition
2. high level supporting tools for the operator as for example graphics simulation, off-line programming, and others, as requested in the NRWS Requirements Document.

12.1 General Purpose NRWS

Figure 15 on page 54 shows the basic overall architecture of the links between general purpose NRWS and control systems. The general purpose NRWS may be connected to the various control systems and can be configured to the specific applications. This means that for n control systems only m (m< n) NRWS are needed. This solution is favoured by JET, it leads to a simple control room layout as shown. The main components in the control room have to be the m NRWSs, eventually a further workstation for the supervisor.

12.2 Special Purpose NRWS

A special purpose NRWS is tailored to the requirements of a specific control system and is not usable for another. For n control systems therefore m = n NRWS are needed independent of the status of the maintenance work (Figure 16 on page 55). This means that in the control room m = n NRWSs have to be installed.).

12.3 Off-Line NRWS

This design alternative of the control lets the workstation degenerate to a non-intelligent interface for the area control. In other words, the so-called task-level (or high-level) control functions are not provided at the operators working place but as a separate unit. In this case the basic operating interface is an integral part of the control system and is not realized in form of a workstation. This interface module contains no intelligent support. If high level operating support is implemented, it is integrated in the control system or, concerning for example planning support, it is put into a separate off-line "workstation" as an independent aid for the operator. The result is shown in Figure 17 on page 56. In the control room in addition to the m = n interface units (the degenerated NRWS), at least m < n off-line NRWS are installed.

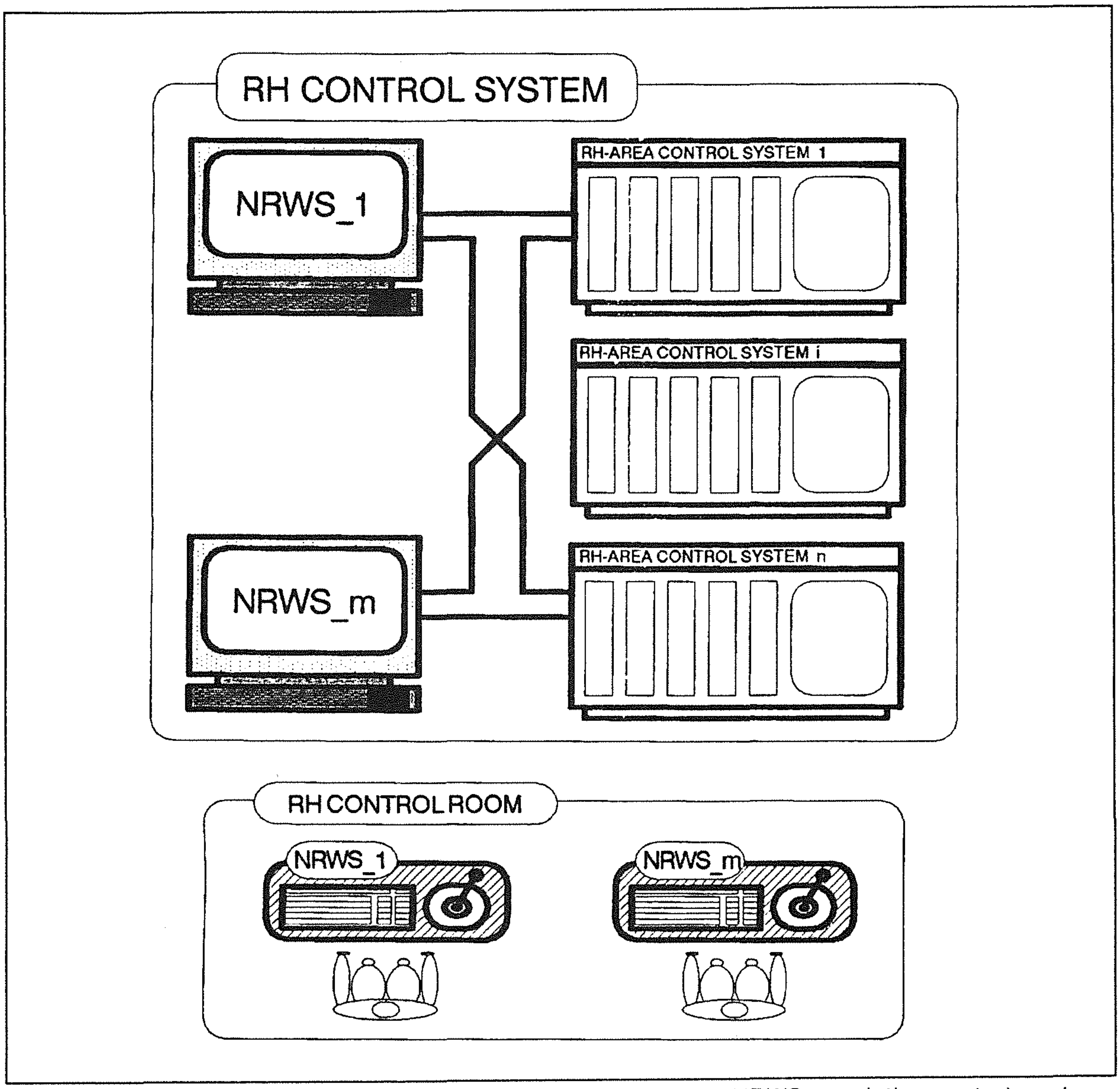


Figure 15. General Purpose NRWS. The links between the NRWSs and the control systems show the possible connections between two General Purpose NRWSs and two control systems.

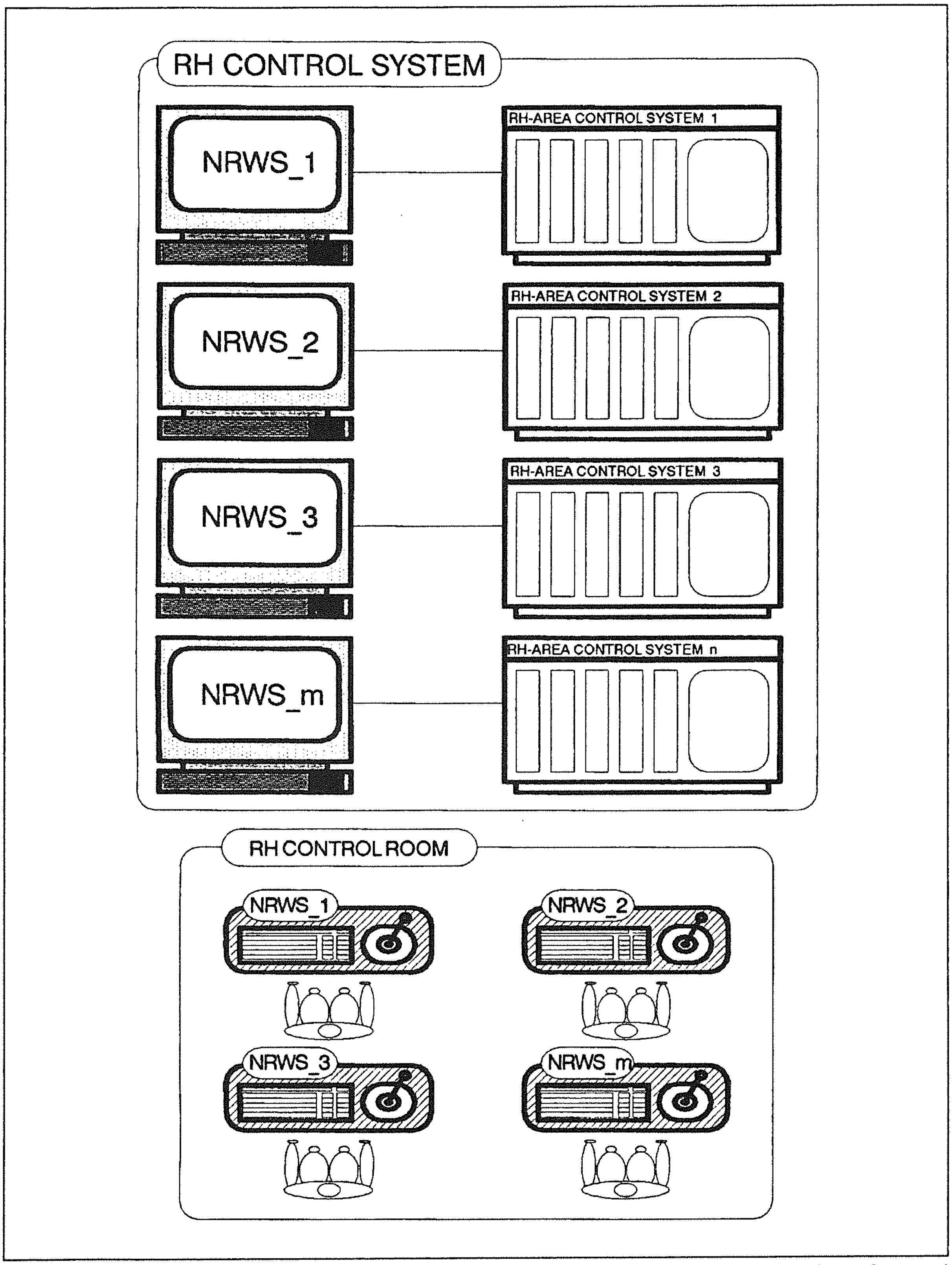


Figure 16. Special purpose NRWS. The number of NRWSs m is equal to the number of control systems n (m = n = 5...7).

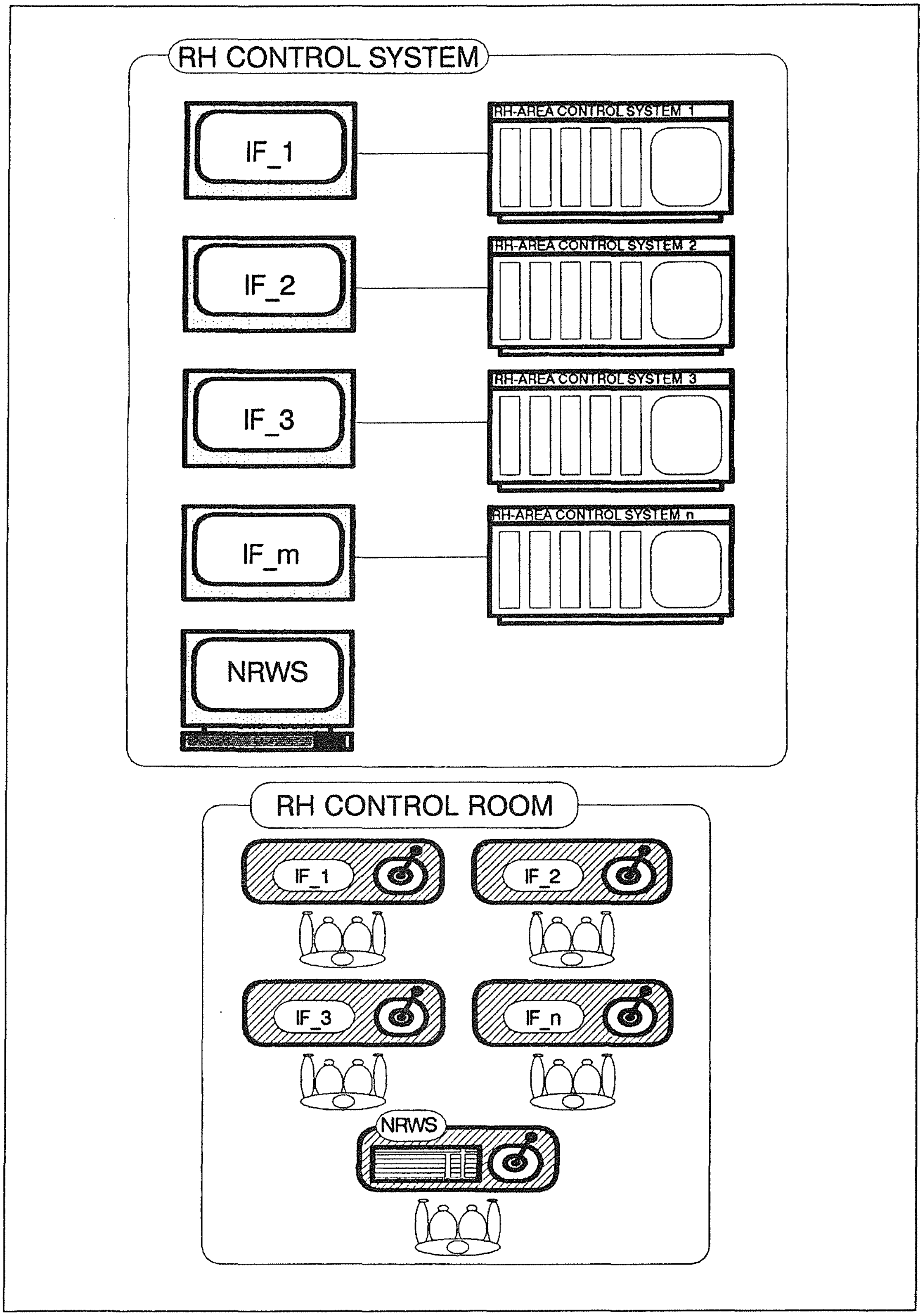


Figure 17. Off-line NRWS. The control system are only directly equiped with a relatively simple operating interface. High level support tools are implemented in the off-line NRWS.

13.0 Trade-off and Discussion

To introduce general purpose NRWSs means implicitly, to prefer software solutions on general purpose hardware using standard implementation tools and interfaces. On the other side the lower the level of functionality the higher will be the speciality of the implementation and the more it is impossible to extract general purpose functions. Therefore control system architectures normally differentiate between the lower motion control level and the task/guidance level control. To implement the task level support as general purpose modules is possible, the question is whether one should implement them as general purpose tools on general purpose hardware, or as special purpose tools on special purpose (control system) hardware and software.

13.1 General Purpose NRWS

13.1.1 Arguments for a General Purpose NRWS

1. Installation of general purpose NRWS provides a higher availability of the control system by redundancy because one NRWS may easily by replaced by another.
2. Standard uniform interface for all maintenance tasks (uniformity).
3. Same interface for training, planning, simulation, and execution.
4. General high level operator tools (e.g. 3D spatial simulation) can be implemented more effectively, because multiple usage reduces costs.
5. Integration of operating interface and high level task oriented operator support systems.
6. The ability of flexible adaption to different control systems includes easy adaptability to new features of a control system.
7. Multiple usage of NRWSs (Mehrfachnutzung), no overloaded (crowded) control room.
8. Special features of operator support (e.g. geometric model and related computational modules can be implemented more efficiently on a special hardware (graphics workstation instead of standard control system hardware, which is optimized for other goals) which is too expensive to be integrated into each control system.
9. The toolbox, provided for the operator, is larger and more easily extendable if not implemented together with the control system. The possibility of finding a suited tool for an unexpected task is larger.
10. A clear separation between task/guidance level tools (as represented by the NRWS) and motion level tools (as represented by the control system) makes control system maintenance and usage easier.
11. Cooperation between RH-areas is easier because communication between equal NRWS is no problem (intrinsically given).

13.1.2 Arguments against a General Purpose NRWS

1. General purpose tools tend to be more expensive because they have to be adaptable to different applications.
2. A general purpose tool has to be configured when another control system has to be attached (time losses, but might be short).
3. It is impossible to use all remote handling equipment at the same time ($m < n$, but not essential, n can be easily increased).

13.2 Special Purpose NRWS

13.2.1 Arguments for a Special Purpose NRWS

1. The tools may be implemented cheaper, because they are used for one specific application.
2. The whole area control may be developed without external restrictions independently of the development of other control systems.

13.2.2 Arguments against a Special Purpose NRWS

1. No flexibility in the architecture includes more difficulties in adapting to new control system features.
2. Provision of models (e.g. geometric models) for high level support is more complex because special purpose tools generally will use special purpose models.
3. The operator (if working with different machines) has to work with different interfaces, the learning effort will be higher especially because the remote handling tasks are performed relatively seldom.
4. Communication between remote handling areas in case of cooperation will be more difficult.
5. The control room will be crowded because as many workstations as control systems are needed.
6. The workstation hardware and software are not used effectively because they are only needed when the related manipulators are used.
7. Hardware and software management will be more costly.

13.3 Off-Line NRWS

13.3.1 Arguments for an Off-Line NRWS

1. The development and usage is completely independent from the control system.
2. Costs of the absolutely needed operational interfaces are minimal.

13.3.2 Arguments against an Off-Line NRWS

1. Starting conditions for simulations can not be taken automatically from the actual state of the controlled system.
2. The development of high level tools integrated into the control system is dependent of and interwoven with the control system development (complicated implementation and maintenance management).
3. Results of a simulation can not be transfered to the control system.

14.0 Recommendations

To combine the advantages of a general purpose NRWS with the advantages of the other solutions a compromise is recommended.

This NRWS consists of

1. general purpose high level operator support modules,
2. special class-specific panels (panel layout),
3. special purpose operating interface modules for each control system, which are runnable on the general purpose NRWS.

These operating interface modules may for example run as well on personal computers representing a "handbox" for commissioning and testing.

The class specific NRWS panels are only needed when TV displays and graphic displays are not exchangeable and if specialized input devices are important.

A first step in this direction is done with the JET-TARM control system. Here the operator's interface is implemented as a special software module on general purpose hardware, a portable PC.

The following guidelines for the RH control system design have to be met, to be able to introduce this compromise of general purpose NRWSs:

1. Control systems (RH-area control systems) should be equiped with
   - their own minimal special purpose operational man-machine interface implemented as a software module runnable in a standardized environment and
   - an additional computer interface providing all status information and the complete functionality of the control system.
2. The control system should be able to execute programs received from the NRWS where they can be developed by off-line programming and simulation. During program execution interventions from the NRWS should be possible.
3. The control system features and the special purpose operating interface module features should be reduced to basic features of motion and equipment control (e.g. functionality of standard robot control systems plus mixed control mode) and, for example, should not include high level or general purpose features as geometric models and related computations.

Summarizing, the basic arguments for a general purpose NRWS of the described kind are:

1. multiple usage of NRWS as far as possible,
2. uniform interface for all operations,
3. provision of a pool of operator high level support tools (e.g. graphic tools, simulation tools),
4. high availability by redundancy (one NRWS can replace another),
5. high performance hardware can be advocated because of multiple usage (e.g. high performance graphic workstations).

Section 4. Design Description of proposed NRWS

15.0 Introduction

As follows from the state-of-the-art report in Section 1, "State of the Art: JET Workstation" on page 1 and Section 2, "State of the Art: Workstations in general" on page 33 man-machine interfaces and operator support in various applications are more and more implemented in the form of workstations. For the remote maintenance of the NET fusion reactor, where a great number of different maintenance tools has to be controlled from one control room the development of a general purpose remote handling workstation is proposed, which can be easily adapted to the different applications by software. The alternatives of a general purpose remote handling workstation are discussed in Section 3, "NRWS Alternatives, Trade-off, and Recommendations" on page 49.

The purpose of this section is to present a functional and architectural framework for the development of a general purpose NET remote handling workstation (NRWS) which represents the only interface between the operator and the remote handling equipment at the remote working site and and which provides the high level operator support software tools. The design is based on Appendix A, "Requirements Definition Document for NRWS" on page 117.

For a better understanding of the design decisions the introduction described the architecture of the RH control system which is the environment for the NRWS. To complete this environmental description also some remarks on the RH control room are added.

These proposals are derived from practical experiences at JET, KfK, and from the related literature. The NRWS and RH control system architecture defines a set of standard modules and interfaces which facilitate software design, development, validation, and test and makes possible the integration of software and hardware from a wide variety of sources. The proposed modularity and standard hardware and software interfaces provide the hooks necessary to incrementally upgrade the system by hardware and software modules which will be available later on and enables a widely independent development of the specified hardware and software subsystems (modules).

The design decisions for the NRWS are influenced by the environment in which the workstation is used. The functional environment is given by the RH control system concept and the spatial environment by the control room layout. To illustrate this NRWS environment the RH control system and the RH control room are introduced before the NRWS design is discussed.

16.1 RH Control System Concept for NET

The **RH control system** is a subsystem of the **NET control system** which consists mainly of the (1) machine control and protection subsystem, (2) the machine diagnostics, (3) the experimental diagnostics and (4) the RH control system (Figure 18 on page 68). The most important RH-areas are:

- IVHU-RH-area (In-Vessel Handling Unit)
- BHU-RH-area (Blanket Handling Unit)
- BMT-RH-area (Bridge Mounted Transporter)
- BCR-RH-area (Main Bridge Crane)
- RHM-RH-area (Reactor Hall Manipulator)

The RH control system itself is partitioned into **RH-areas**, representing a set of RH equipment grouped around a major device Each RH-area has its own **RH area control system** organized as a hierarchy of computers and controllers dedicated to one RH-area. To run a RH area control system in the operational phase a NRWS is needed.

The KfK proposal for an overall NET remote handling control system concept is documented in [59]. The basic goal of the RH control system development is to implement a man-in-the-loop concept because in contrast to industrial applications in the maintenance area of work a fully automated performance of the work will not be possible. Therefore a mixed-mode control is needed allowing for manual work which might be supported by the control system (computer) and for automatic work which is supervised by the operator. The control system has to enable a close cooperation between man and machine characterized by mutual help and mutual supervision and optimal use of the cognitive and manipulative abilities of the operator. Figure 19 on page 69 shows the integration of the operator into the control flow. The operator is provided with a complete state presentation using TV, graphics and standard data presentation techniques.

To guarantee highest operational flexibility the operator has access to all levels of control. In the basic case of operation the operator has access to the lowest sublevel of motion control, the joint control level. This is usually realized via a master of a master slave manipulator. On the path level of motion control (the next higher level) controlling is done for example via a joystick. Control on the task control level means to control the system using commands starting complex preprogrammed motions or using other high level support modules of the control system or the workstation. In general the different hierarchical levels of the control system separate stepwise more task specific functions from more equipment specific ones.

The control system is designed as a hierarchical control system. This type of system is sometimes called supervisory control system because the operator in the automatic mode supervises subtasks and in the manual mode the control system supervises the operator. This control system architecture is in accordance with the NET Control System architecture (naming the levels "Central", "Area", "Local", [61]) and with the EC TELEMAN architecture and reflects the common sense in the telerobotics field.

The hardware and communication architecture of the RH control system is shown in Figure 20 on page 70. On the lowest level, the local controllers provide basic equipment control of equipment like for example the IVHU, the cameras, the work units and

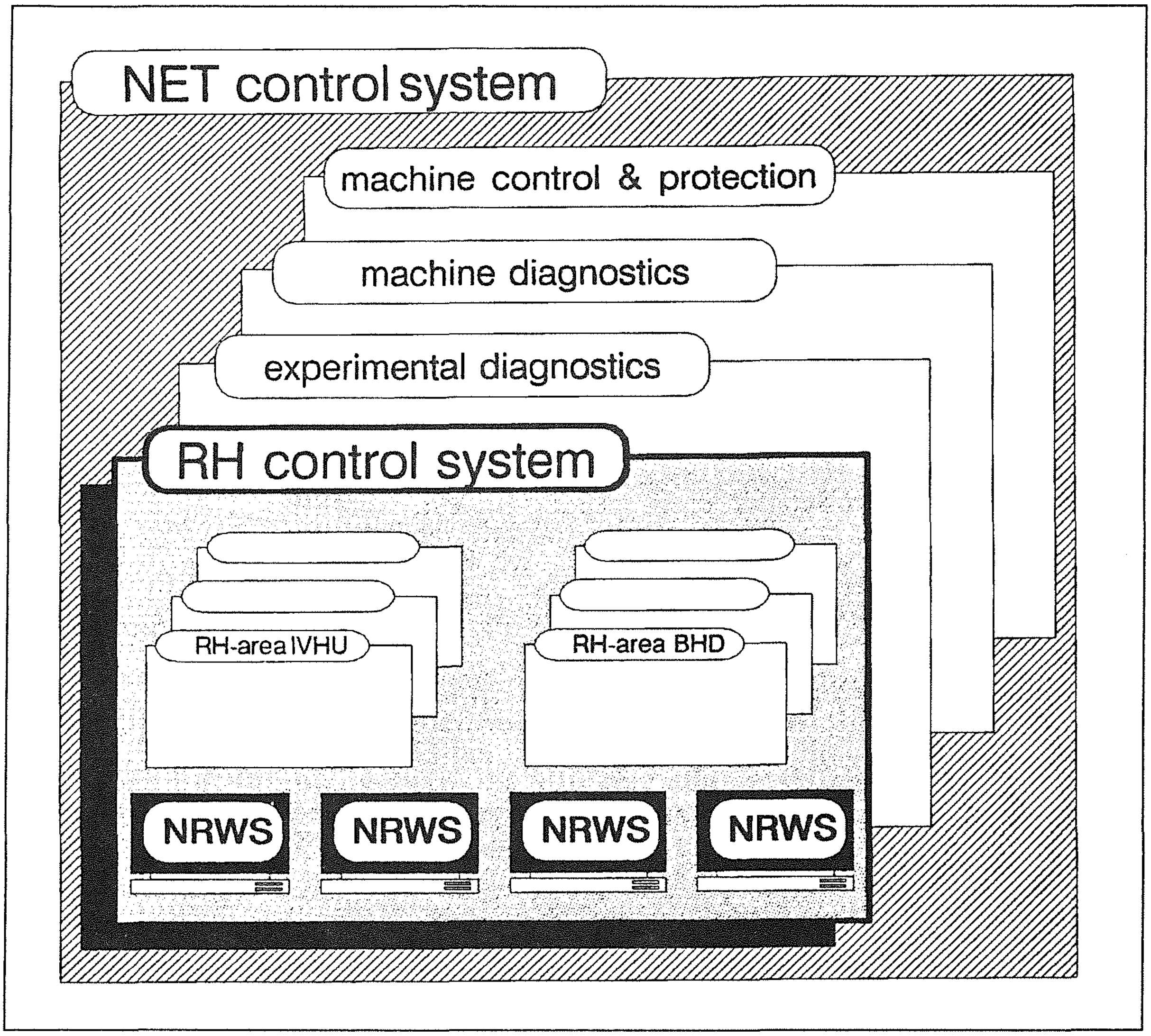


Figure 18. NET control system architecture. The RH control system is a subsystem of the NET control system. The RH control system itself is partitioned into RH-areas. To run a RH area a NET remote workstation (NRWS) has to be attached to the RH-area control system.

others. On these controllers run typically closed motion control loops. All the local/equipment controllers of an area (e.g. boom controller, work unit controller, camera controller) are coordinated, as far as needed, by an RH-area controller. The RH-area controller shall run RH-area specific subtasks to make the NRWS as task independent as possible. An example for a subtask which may be implemented on the RH-area controller would be a operating interface of a local controller (19.3.2, "Operating Interface" on page 105), the motion path management, or the management of local control system parameters. Communication in an area is done via a separate RH-area bus. During operation of a RH-area a NRWS is attached to the RH-area. The NRWS may communicate directly with local controllers or via the RH-area controller. Coordination of RH-areas is organized via the RH-bus which connects all NRWS. Via this RH-bus all NRWS have access to central utilities like CAD, model and resource management, and the procedure data base. These central utilities are partly NCS wide services with decentralized resources.

The functions of the task control level are implemented on the NRWS, the functionality of the RH-area control is implemented as dedicated RH-area control systems.

The RH bus is connected via a bridge to the NET control system. The RH control system forms a subsystem of the NET control system. As a result of this integration all the general requirements and basic design decisions for the NET control system are valid for the RH control system as well[61] [62]. They will not be discussed or mentioned in detail in this report. This report is focussed on the RH specific characteristics of the RH control system.

Both bus types include audio and video channels which need not be implemented on the same hardware (separate lines).

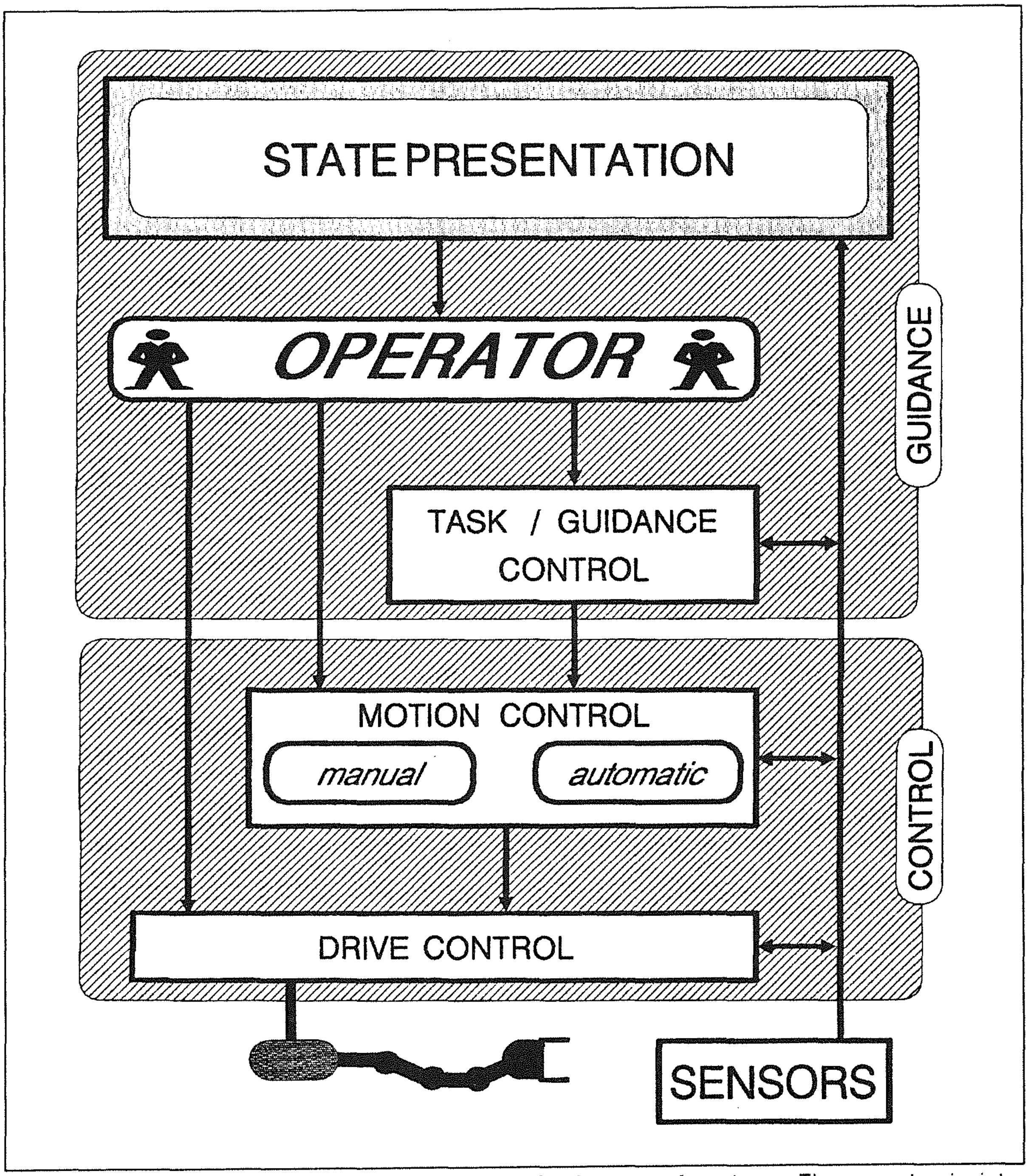


Figure 19. Architecture of control and data flow in the control system. The operator is integrated into the control loop by providing him with all status informations and giving him the possibility of acting on the task control as well as on the motion control and drive control level. The functions of the guidance level are implemented on the NRWS, the functions of the motion control level run on the local controllers and/or the RH-area controller.

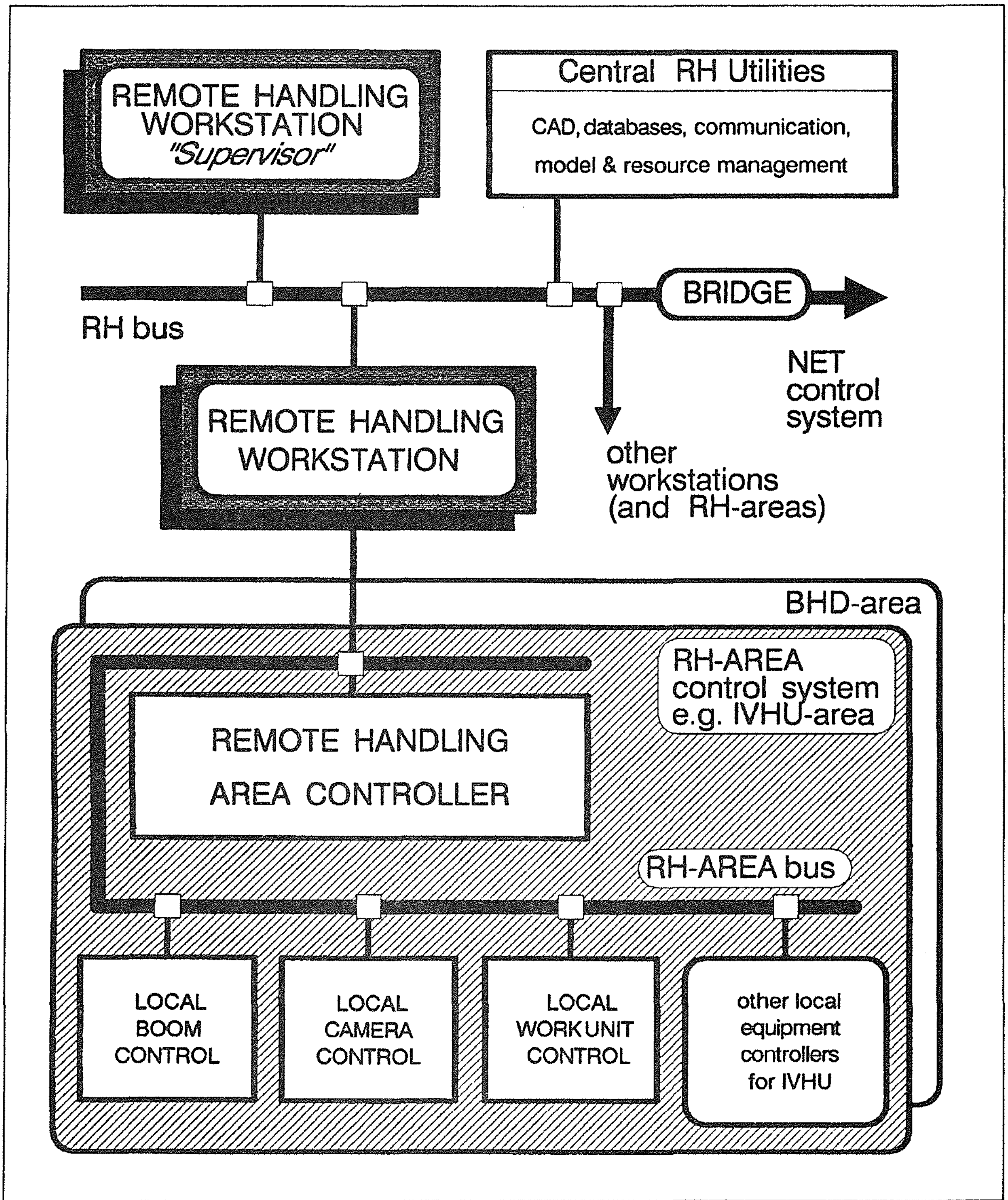


Figure 20. Computer & communications architecture. The RH control system is partitioned into RH-areas with an area controller coordinating the activities of the various local or device controllers of the area. Intra-area communication is done via a separate RH-area bus (LAN). To run a RH-area a NET remote handling workstation is attached to the RH-area controller. The NRWS represents the task level of the control system. Communication of NRWS with each other or with the central RH utilities is done via the RH bus, which is bridged to the NET control system. The central utilities are services integrated with the NCS-wide data management with distributed data bases.

16.2 Remote Handling Control Room

Experiences in practical remote handling work show that usually at least two operators are working together on one problem with one major equipment. Because of the different skills needed for the different tasks one operator, the executing operator, is performing mainly the direct manual work (e.g. master-slave operation, transporter movements) and the other, the supporting operator, does subtasks (e.g. camera control, on-the-spot planning,surveillance). The NRWS is designed for two-operator work but for some applications for one operator as well. In the latter case the interface (the panel) is configured for one-person handling. If the work of two areas (e.g. IVHU and BHU) has to be coordinated the NRWS provide information about the status of the parallel process in a separate window if necessary. The work of one or more teams may be supervised at a separate NRWS configured for this purpose. The supervisor may login to each control process for selected status information.

A special problem in control room design is to find a solution for communication between the operators. Of course the executing and supporting operator will communicate directly and by pointing at the screens. The communication between different teams and/or the supervisor may be done, for important facts, formally through the NRWSs by a message transfer service. For this kind of communication the NRWS will provide a special operator-operator communication subsystem with predefined messages and additional form-free messages.

An additional communications medium is a large common screen, composed of video projection areas and a display (e.g. liquid crystal) for status and message display. This type of communication is important and helpful in cases where pictorial information is needed. For working with these large screens each team has a laser pointer available for pointing at the screens, for pointing at the data display, each team has its own cursor.

The arrangement shown in Figure 21 on page 72 shows the abstract functional concept, Figure 22 on page 73 shows a layout example using standard control room components. Both are based on the preliminary assumption that for each class of work at least one working place should be available. These pictures shall only give a very first impression and shall be a basis for control room layout discussions.

This scenario is based on the assumption that a separate RH control room (separated from the general NET control room) is the best solution because the RH team is working relatively independent.

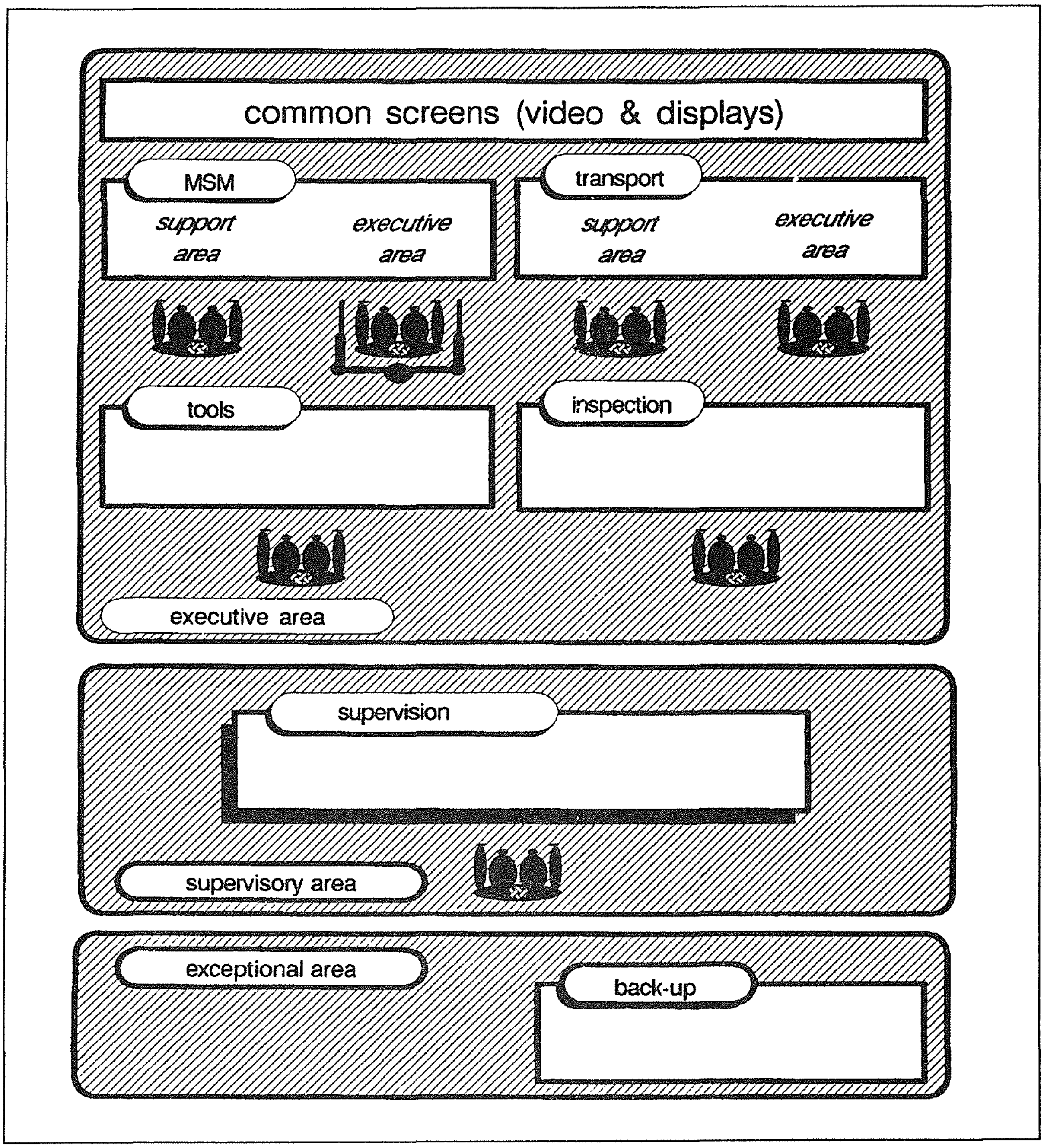


Figure 21. Remote handling control room layout (functional). This functional layout only shows the different components and working areas which have to be considered in a spatial layout. At least one workstation of each type has to be provided.

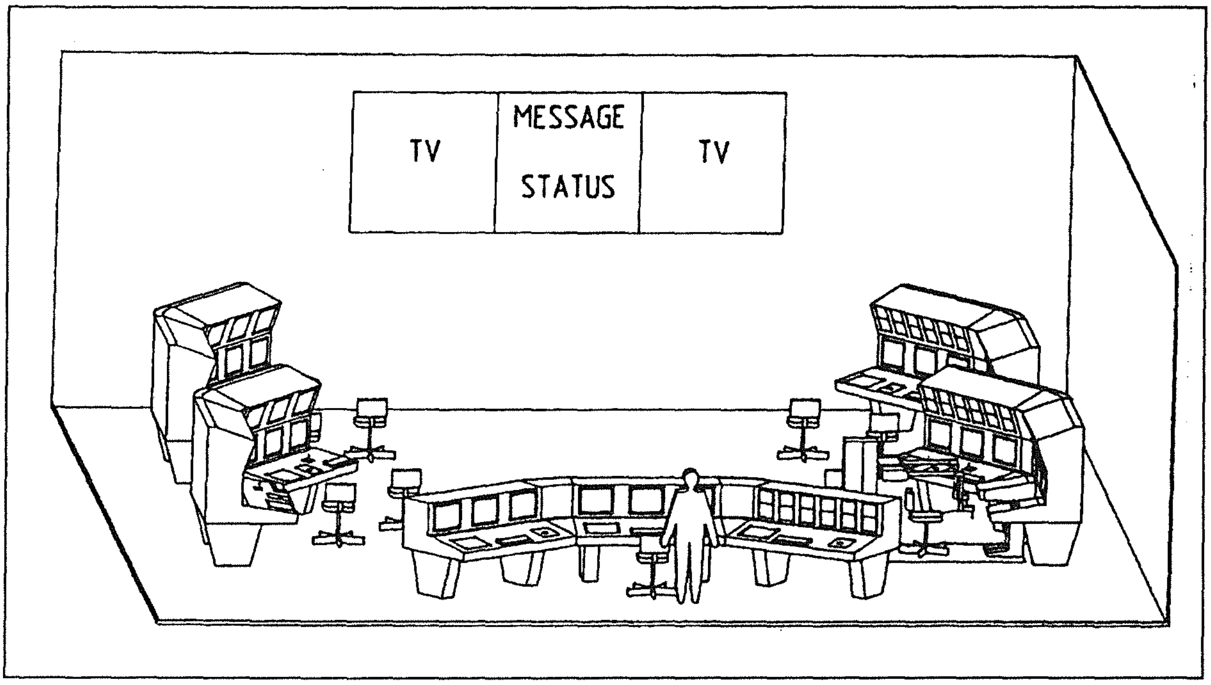


Figure 22. Remote handling control room layout (spatial). Layout example using standard control room equipment and showing one workstation of each type. This spatial layout is not the result of ergonomical investigations, but only a first approach, showing a possible arrangement of components considering communicational aspects.

17.0 NRWS Functionality

The NRWS is a system which integrates heterogeneous operator support modules (on different computers) and the operating interface of the RH-area control system into a homogeneous working system, accessible from one working place. The central system accessible via the workstation is of course the RH area control system. The NRWS itself provides functions directly supporting the operator in solving the maintenance tasks.

The generic functionality of the whole control system allocated to the three functional levels of the system is shown in Figure 23 on page 76. The main functions on the NRWS representing the tasking/guidance level are:

- man-machine interfacing
- integrated viewing
- off-line planning/programming
- monitoring
- guidance
- training
- communication, dialog management
- simulation
- logging
- configuration

These functions of the NRWS are discussed in detail later. The functionality of the RH-area control system (or simply the control system) in this context illustrates the border between the NRWS (the guidance system) and the control system:

- basic motion control (closed loop control)
- single command execution (manual mode)
- program execution (automatic mode)
- on-line teach/repeat
- backtracking
- operator support functions (e.g. jigs, motion on a surface)
- logging of motion level actions

The drive control level simply provides the function of basic motor control in form of a single joint velocity control.

For the purpose of testing, maintenance, and commissioning or in case of failures the two lower level subsystems have simple interfaces to be able to run them locally.

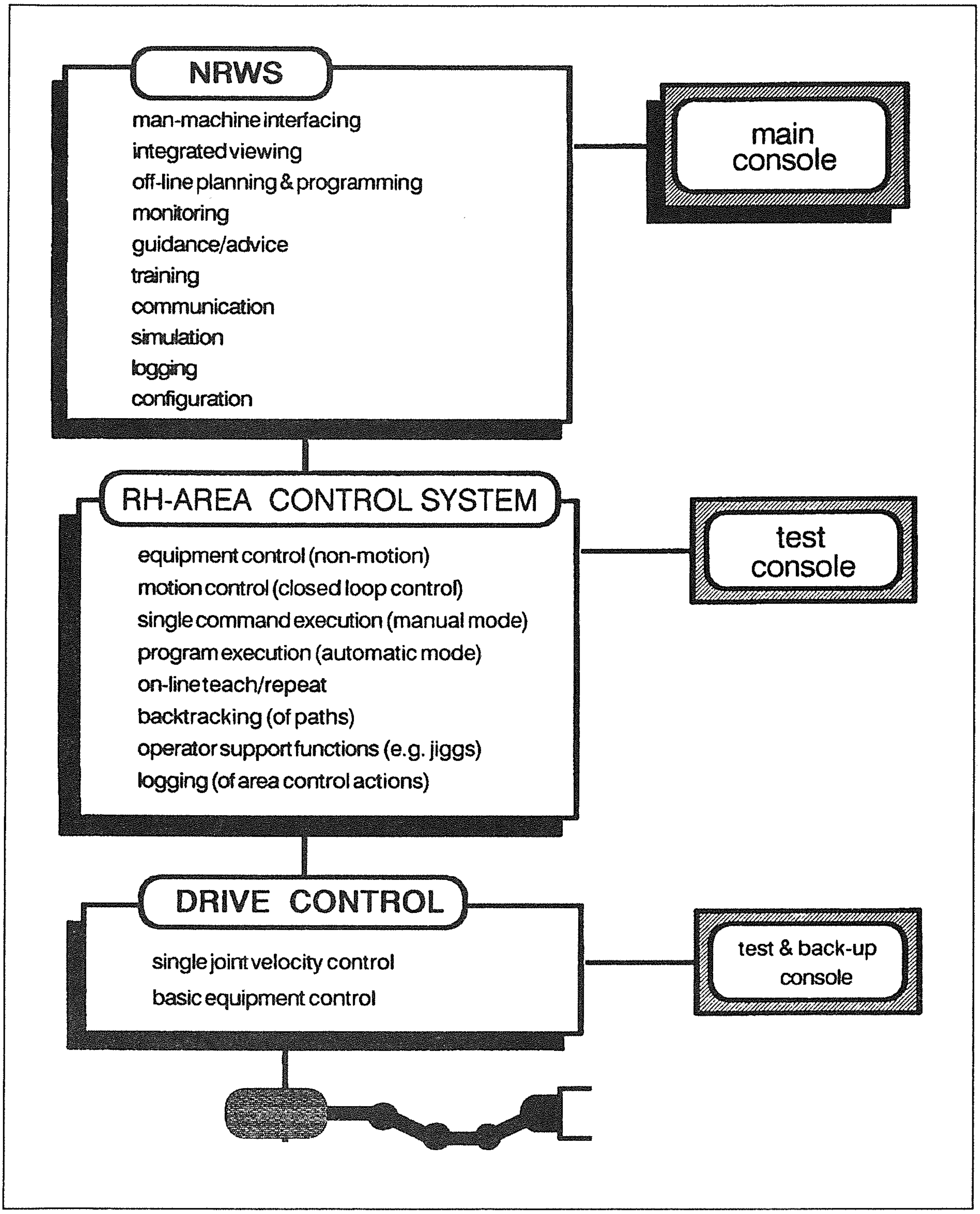


Figure 23. Functionality of control system levels. The NRWS represents the task level support and the man-machine interface, the RH-area control system represents the motion control level

17.1 Man-Machine Interfacing

The complete man-machine interface for the operators during normal operation (maintenance) is realized on the NRWS. The motion control level (the RH area control systems) only possesses a test interface. In a broad sense the NRWS represents the man-machine interface, but strictly speaking, the man-machine interface consists of the operating panel and a so-called UIMS (user interface management system), a software module, managing the basic interaction between man and machine and which enforces a unified appearance and usability of the interface (Figure 24 on page 78). A UIMS in its simplest form is a window manager with a related toolkit providing software tools as for example a tool for implementing a menu system. Using such a toolbox for the user interface implementation reduces the effort required to create high quality user interfaces. It helps to ensure consistency among the user interfaces of different applications and makes enhancements easier. The user interface in this sense is not concerned with semantics but only with the input/output device management and the presentation of basic dialog data.

Special attention is payed to the concrete command input (textual, menus, speech, function keys etc.) and the exchangeability of various devices for input of geometric data (one-to-one master devices, joysticks, dials, keys etc.)[1] . All the input and output devices for one NRWS are integrated into the NRWS-panel. There is one exception: The most important input device which plays a special role: the master of a master-slave manipulator. This device will not be integrated into the general panel due to the separated control system (high bandwidth for low level control). But this subsystem has to be integrated spatially into the panel because the master-slave operator has to use the standard NRWS as well. This integration is mainly an ergonomic problem and is not subject of this paper (20.0, "Future Work" on page 111).

The design of the panel architecture is done according the X-WINDOW client-server model "Definition of terms and background informations" on page 141, whereby the panel is implemented as a server as shown in Figure 24 on page 78. This architecture which includes a user interface management system (UIMS) provides a great flexibility and manageability of hardware and software. It is a widely accepted architecture which separates the input/output devices and the man-machine interface (dialog) subtasks from the application programs. It provides a freely selectable allocation of windows on screens and attachment of devices to functional modules of the NRWS. This architecture should be understood as a guideline for the future. For short term developments the busses have to be bypassed for some high bandwidth connections.

This architecture is able to provide a wide variety of input and output devices, such that for a special application or for a special operator a choice is possible. This is especially important in the first applications and during tests. For the execution of maintenance work the number of different input/output devices should of course be minimized. this should be possible in the near future for the displays as well by using one type of screen for graphics, mimics, and TV output.

17.2 Monitoring

Monitoring means to supervise or to check the work sequences by the operator or automatically by program. Monitoring is done on all levels of the control system, on the drive/equipment control level as well as on the motion and tasking (guidance) level. Monitoring by the operator demands a problem suited status presentation, well structured to support the cognitive abilities of man. This is part of the general man-machine interface. Various windows allow for viewing onto different kind of presentations of the state of the equipment and the environment. The automatic monitoring is based on the preplanned procedures, motion paths, or on lower levels, simply on boundary values. Deviations from these preplanned sequences or values may be detected by algorithms and signaled to the operator. This high level monitoring is done on the NRWS, lower level monitoring is in detail done on the control system and simply signaled to the NRWS and the operator.

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[1] A very important input device especially for the MSM operator is voice input. KfK has some experience in this area (CATSYS and DISTEL projects) and will implement and investigate voice input for EDITH control.

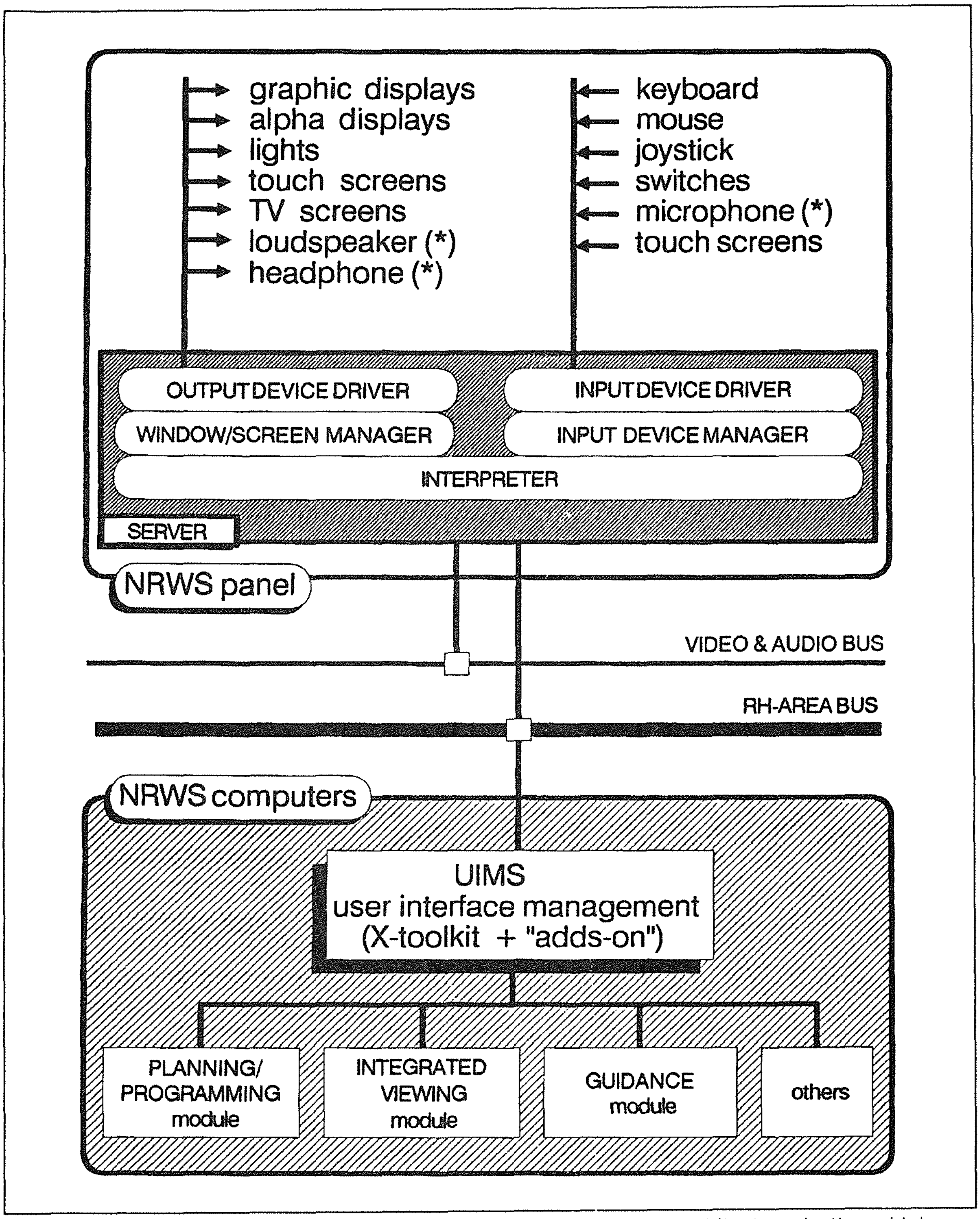

Figure 24. NRWS-panel implementation architecture. The basic architecture is the widely accepted X-window client-server architecture providing network wide device independence. The UIMS (user interface management system (UIMS) serves for decoupling the user dialog management from the application modules. Interfacing is thus treated as a separate task which unifies the interface and makes enhancements or special adaptions easier. The video and audio devices (*) are not part of this server architecture but handled separately. The master of MSM systems is not included because of its specific implementation and its low level (high bandwidth) interface.

Monitoring in the NRWS context is partitioned into three groups which are differentiated related to the implementation (modules) and related to their appearance to the operators. At first there is the **functional monitoring** which is known from the power station control and which is dedicated to monitor the right functioning of the equipment and to maintain a steady state of processes. In contrast to a power station, in remote handling complex maintenance procedures have to be performed by the operator and therefore the special **procedural monitoring** is provided as a special monitoring section. The third type of monitoring concerns the performance of maintenance work in a complex environment with kinematically complex equipment. The **spatial monitoring** supports the operator in doing the manual motion control properly at the remote working site. In this context the most important tool is viewing and therefore viewing is discussed in a separate chapter (17.3, "Integrated Viewing" on page 80).

In all three aspects the NRWS differentiates between

1. monitoring by operator supported by a problem suited state presentation by

   - procedure visualization,
   - scene visualization,
   - functions (process) visualization

   and

2. automatic monitoring: detection of failures by special modules

According to the state of the art monitoring by man is considered as the central monitoring procedure, automatic monitoring is being investigated in the context of procedural and spatial monitoring. Only some few automatic sub-procedures are available (e.g. collision detection).

17.2.1 Spatial Monitoring

Spatial monitoring means to check permanently whether geometric or kinematic restrictions are not violated. If the operator is working manually he will be supervised by the control system based on the kinematic/geometric knowledge (CAD-model), and special knowledge about restrictions in special working phases.

Spatial monitoring by the operator is supported by providing various synthetic three dimensional views of the scene as an addition to the camera views (17.3, "Integrated Viewing" on page 80). This most important type of spatial monitoring is provided for the operator as a special tool: the viewing subsystem.

In contrast to viewing the spatial monitoring presents the equipment and the working site additionally in a more abstract way by mimics or topographic maps.

The central type of automatically done spatial monitoring is *collision control* based on joint angle sensors and the geometric/kinematic model. This type of collision control is especially valuable in an working environment with restricted sensor usage.

17.2.2 Procedural Monitoring

The base for procedural monitoring is a computer internal model of the preplanned procedures and a set of rules and restrictions which have to be obeyed during the performance of unplanned work. The monitor checks on the base of signals from the RH-area control system and messages on the progress of work from the operator whether the actual state of the maintenance process is in accordance with the planning. The information needed is in this case mostly based on an administrative process: the operator has to acknowledge the reception of advices, to respond on questions, and to signal the completion of a subtask. As in spatial monitoring, the most important type of monitoring is monitoring by the operator who is supported in his work by a meaningful graphical presentation of the state of the maintenance process.

17.2.3 Functional Monitoring

This type of monitoring is known best from power stations where the operator is provided with various abstract presentations of the plant and the equipment. This type of monitoring is more or less equipment oriented. The system presents the equipment and devices in an abstract way by mimics, flow diagrams, meters, and annotated values to show the functional state of the subsystems. It is a control task oriented presentation of all the signals coming from the equipment. In addition to this state presentation for monitoring by the operator, there are several means for value and/or trend surveillance by the monitoring system automatically. This is important because the number of values to be handled will be very large. This automatic submonitoring will call the operator's attention to the area of actual problems by provision of a graphical presentation of the context of the problem.

17.3 Integrated Viewing

As the most important subtool in the context of monitoring (17.2, "Monitoring" on page 77) this functional module (Figure 25 on page 81) combines viewing by CCTV with synthetic scene presentation by 3D computer graphics. The computer graphics presentation itself is used for advanced camera control as well: e.g. pointing at a point of interest using the cursor instead of a velocity control of the camera positioning device in a conventional system. One special feature in this context is camera tracking. Camera parameters in form of the viewing pyramid are overlayed on the synthetic scene, facilitating the usage of cameras and interpreting camera images. The actualization (updating) of the environment and equipment models is based on sensors, as far as possible, or on administrative procedures for the operator. The standard sensors that will be used are: the joint angle sensors, distance sensors, contact sensors, assembly state sensors, inclination sensors, and bending sensors. The type of displays are: (1) high resolution graphic displays for 3D graphics, stereo graphics, and integrated TV images, (2) standard TV displays, (3) stereo TV displays, (4) standard graphics (2D) for control purposes (e.g. camera control). A first implementation of this concept was done at JET by KfK for supporting the JET boom operator (GBsim, Figure 26 on page 82). The second enhanced version of the KfK system, called KISMET (Figure 27 on page 83), will support the JET TARM operator. To support the IVIS operator GBsim was combined with the IVIS control by JET.

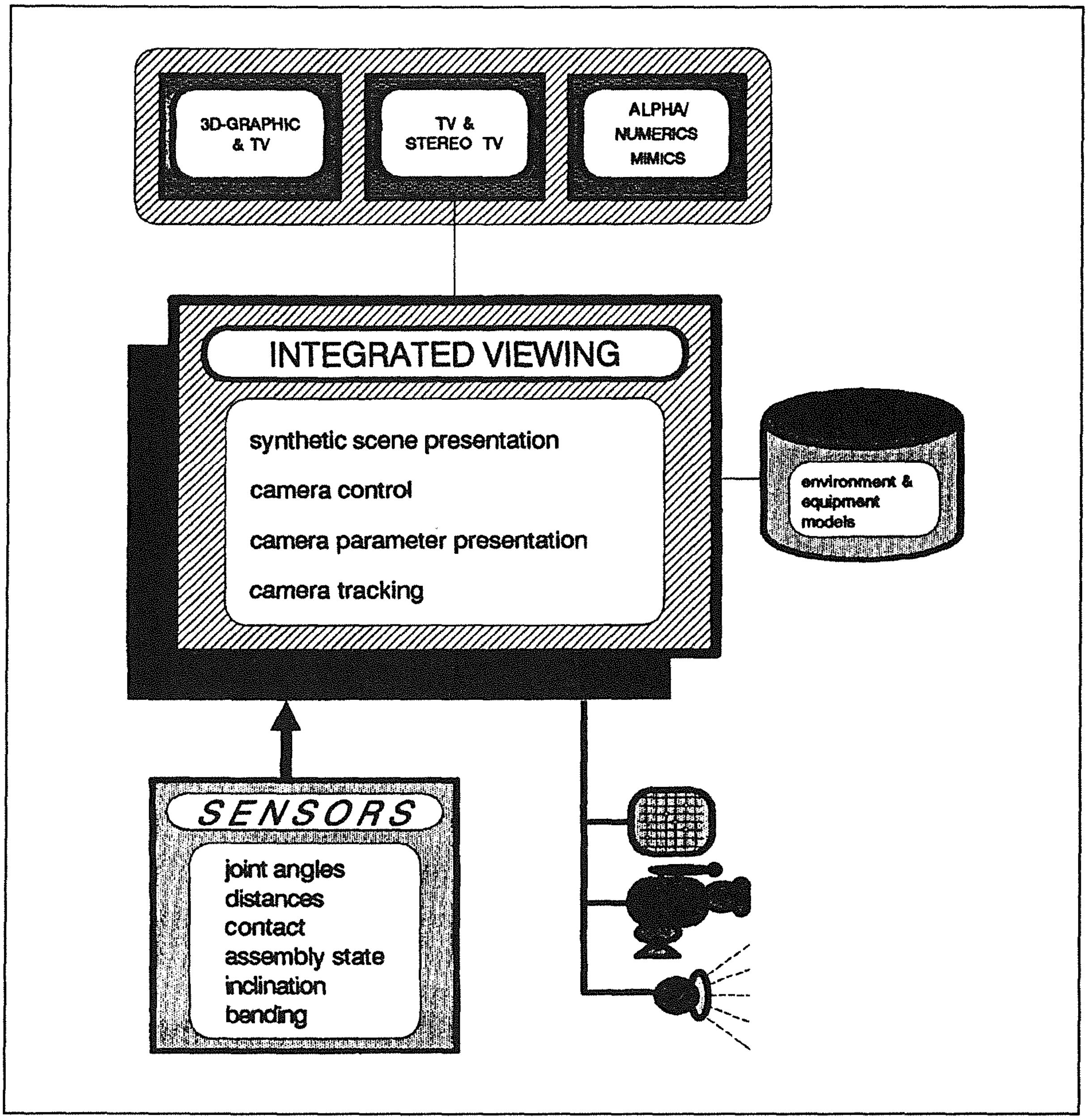

Figure 25. Concept of integrated viewing. The integration of artificial viewing using sensor controlled computer graphics with standard TV unifies and simplifies the work of the camera operator. The goal is to provide one tool for one function.

17.4 Guidance

The purpose of this module is to lead the operator step-by-step through a successful execution of a high level task. The operator will be guided through preplanned task sequences by presenting textual or symbolic instructions to him step-by-step with proceeding task execution. This function will be done by a so-called **guide/advisor** module, that gets its "programs" from the human task planner in the form of **task-nets** which are the base for procedural simulation and guidance. This type of guidance through a procedure is accompanied by context information, showing the previous step, the actual step (running) step, and the next required step. These elementary advices ("do this", "do that") completed by a more or less detailed graphical presentation of the task-net. Nets are needed because there often are parallel subtasks in maintenance processes. Besides the single actions which must be done, the net presents conditions which are needed for performance of an action. The result of an action is presented as change of conditions. Conditions in this context may be the availability of a tool or the preparation of a work site. The level of detail in procedure net presentation is variable: subtasks

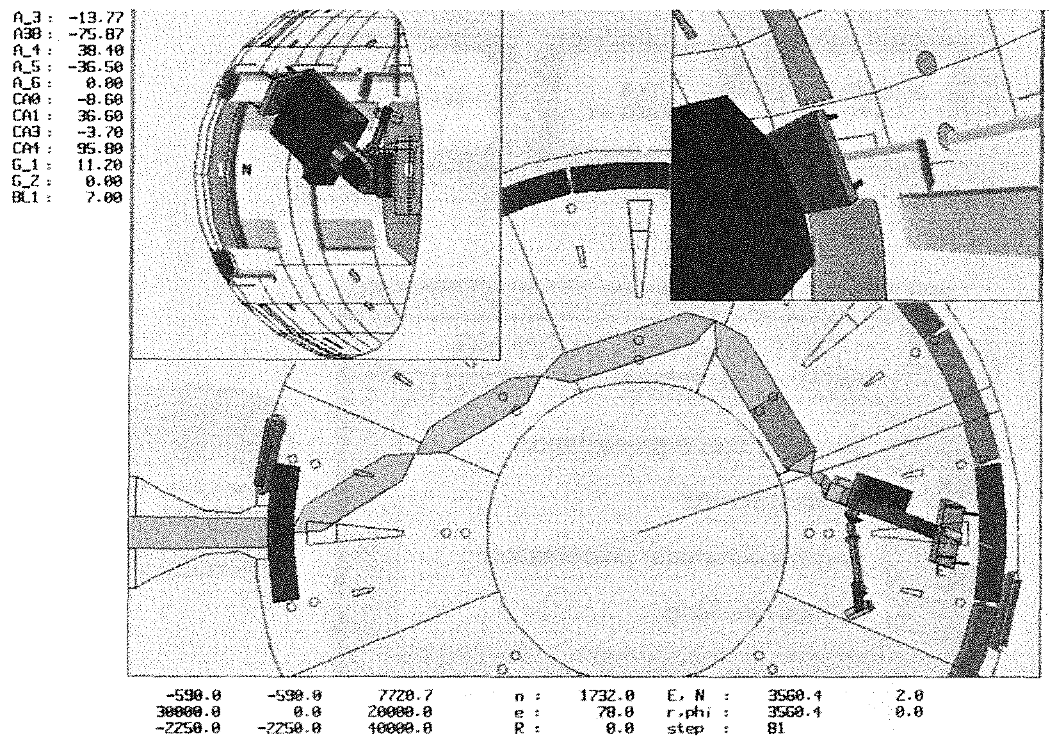

Figure 26. GBsim display example. The figure shows a basic top view of the mid plan of the JET torus, a side view (up left), and a simulated camera view (up right)

may be presented as net nodes or as subnets if more details about the subtasks are needed.

This guidance system is interactively usable. It is an intelligent operations handbook with the possibility of making notes for each action or condition (annotations).

A basic feature of the guidance system is the task oriented HELP-facility. This means that the operator can ask the system for explanations to an action or condition to find out how or why he has to do a task. He can also ask whether he has to obey something or whether there may arise special problems. He may of course have a look into his own notes attached to an action or condition. The HELP facility is structured and context sensitive. HELP is given according to the actual state of the work and is given according to the kind of question (why?, how?, why not?, attention?, learned?).

In case of deviation from the preplanned procedure the advisor has to have some intelligence to re-specify the procedure that means

- to clarify the type of deviation,
- to find or propose suited maintenance procedures,
- to specify the resources.

A special kind of guidance is the simulation of the next required steps. This is done by a procedural simulation going through the action net, the related spatial simulation showing the motion of the equipment in the working environment on the graphics screen in three dimensions, and if needed a functional simulation, showing the changing of various equipment values during execution. This ad-hoc simulation of normally short sequences may be coupled with and enhanced by related video takes if available (multi-media presentation).

In the first stage of the guidance system (according to the state of the art, guidance is only based on preprogrammed (preplanned) procedure and motion descriptions. In fu-

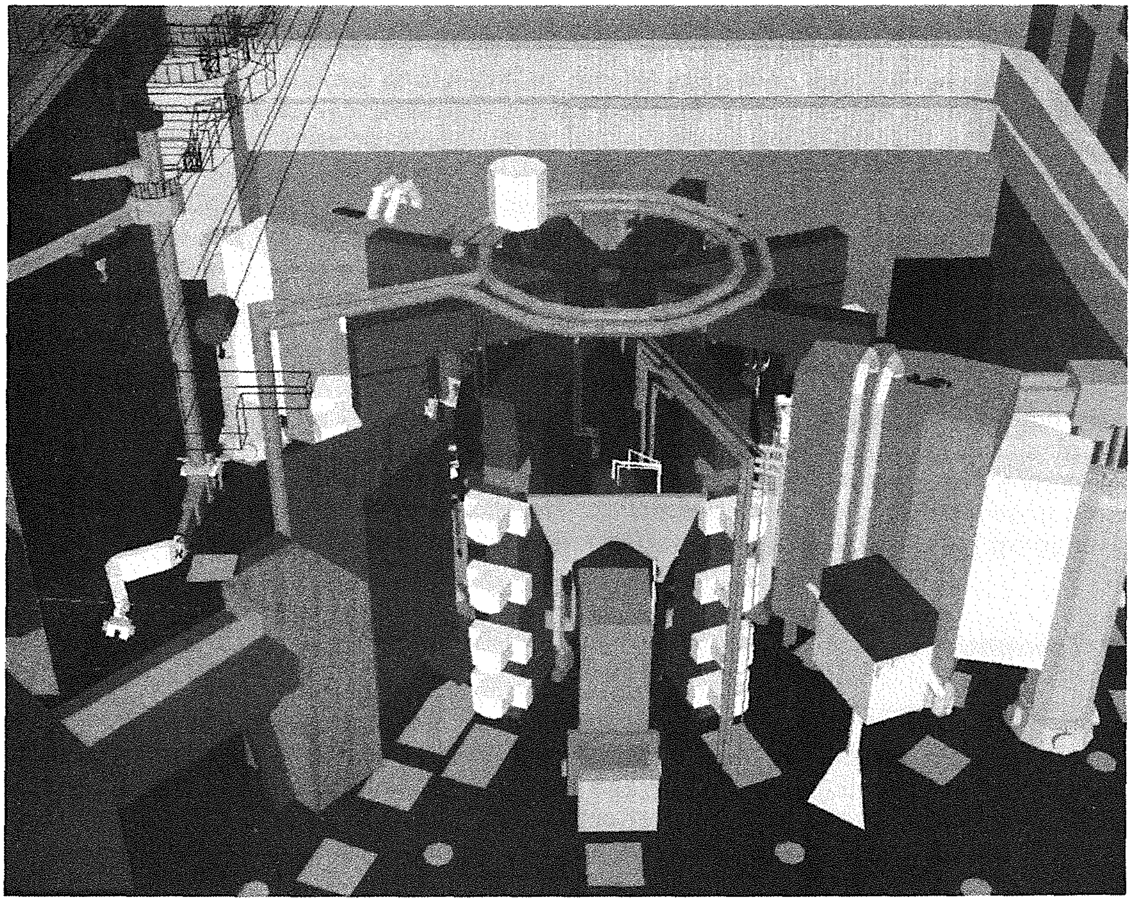

Figure 27. KISMET display example for JET-TARM control. The display shows a birds eye view of the JET torus (ex-vessel view) and the TARM (left hand side)

ture versions the usage of knowledge based support techniques may be used to help the operator also in unplanned situations or to make the guidance system adaptable to special work phases or to the behaviour of the operator. Then the informations requested explicitly by the operator will be presented automatically. The support proposed may be called an "**Intelligent Handbook**".

17.5 Planning, Programming

Planning is understood in this context as an interactive process involving the planner and supporting planning modules. The planning system is a planning support system, in the future those may be completed by subsystems for automatic planning. Planning and programming is done on two levels: the motion control level and the task or procedural level of control. Motion or trajectory planning and programming results in programs for the motion control subsystem. This is similar to off-line programming of industrial robots, but has to include the special features of the remote handling (RH) motion controllers. But there is one additional aspect, the **ad-hoc programming** (on-the-fly programming). This means, usage of off-line programming in unforeseen situations, where in conventional systems the operator would work directly on-line. In these cases fast off-line programming by off-line teaching on a simulator will make the execution safer because the solution of the handling task was simulated. This is especially helpful in situations where a solution is not obvious. The term ad-hoc programming shall include all the facilities required for a fast programming and testing cycle to generate immediately needed programs.

On the task level, where no automatic execution is envisaged until now, planning means to decompose tasks into simple subtasks or action steps, including allocation of resources and coordinating communications with other RH sections. The result of this work are graphs composed of actions (subtasks) and conditions (states) which have to be true for starting an action. At the completion of an action other conditions are changed, to represent the new state of the maintenance process. These **action nets** (Petri-nets, modified Petri-nets), suited to express concurrency, conflicts, and dependencies, are used in the execution phase to guide the operator step by step through complex work sequences which have to be done without failures. The advices will be presented to the operator as textual advices which may be completed by a graphical presentation of the action net showing the whole context of the actual subtask (Figure 28 on page 85). This abstract presentation may be graphically accompanied by scene presentations (see "Guidance"). The very general modelling of procedures by Petri nets can be completed by other more specific representation tools as GANTT charts[2] or standard CPM representations[3] .

On this high programming level not only the actions needed for maintenance tasks are used but also actions related to the NRWS modules may be included in the "program". For example the start of a new action may be accompanied by the activation of a new window showing the context of the action. In this sense the high level planning and programming includes all activities and functions used to perform the task.

17.6 Training

Because of the lack of a full mock-up or the cost of mock-up usage, the NRWS provides a training module including procedural, spatial, and functional aspects of the maintenance tasks. The training is based on the database of preplanned RH procedures, preprogrammed motion paths for a spatial presentation of the tasks to be trained, and the simulation of various signals and messages of the equipment. The preprogrammed motion paths are mainly used for visualization of work sequences the operator has to perform manually. Only a subset of these preprogrammed motion paths may be used for automatic execution by the control system in the task execution phase. To train the operator the training subsystem presents to the operator a complete simulation of the tasks to show him what he has to do. These demonstrations will be interrupted to ask the operator for manual performance of demonstrated subtasks. In all stages of the training the trainee may stop the demonstration and ask for replays or for explanations. The training subsystem will of course also use the advisor subsystem.

The training subsystem is a combination of active performance and studying an intelligent handbook (manual) including the dynamic presentation (simulation) of the tasks to be learned.

17.7 Configuration

Configuration means preparation of the workstation and the RH-area control system for a special maintenance task. The following subtasks are differentiated:

- Activation of the problem suited screen layout
- Activation of the required databases
  - RH procedure DB containing the procedures to be performed
  - model DB containing the spatial models of the actual task

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[2] GANTT charts show the sequence of subtasks and resource allocations over a time axis.

[3] The standard Critical-Path-Method's presentation for task management is a network.

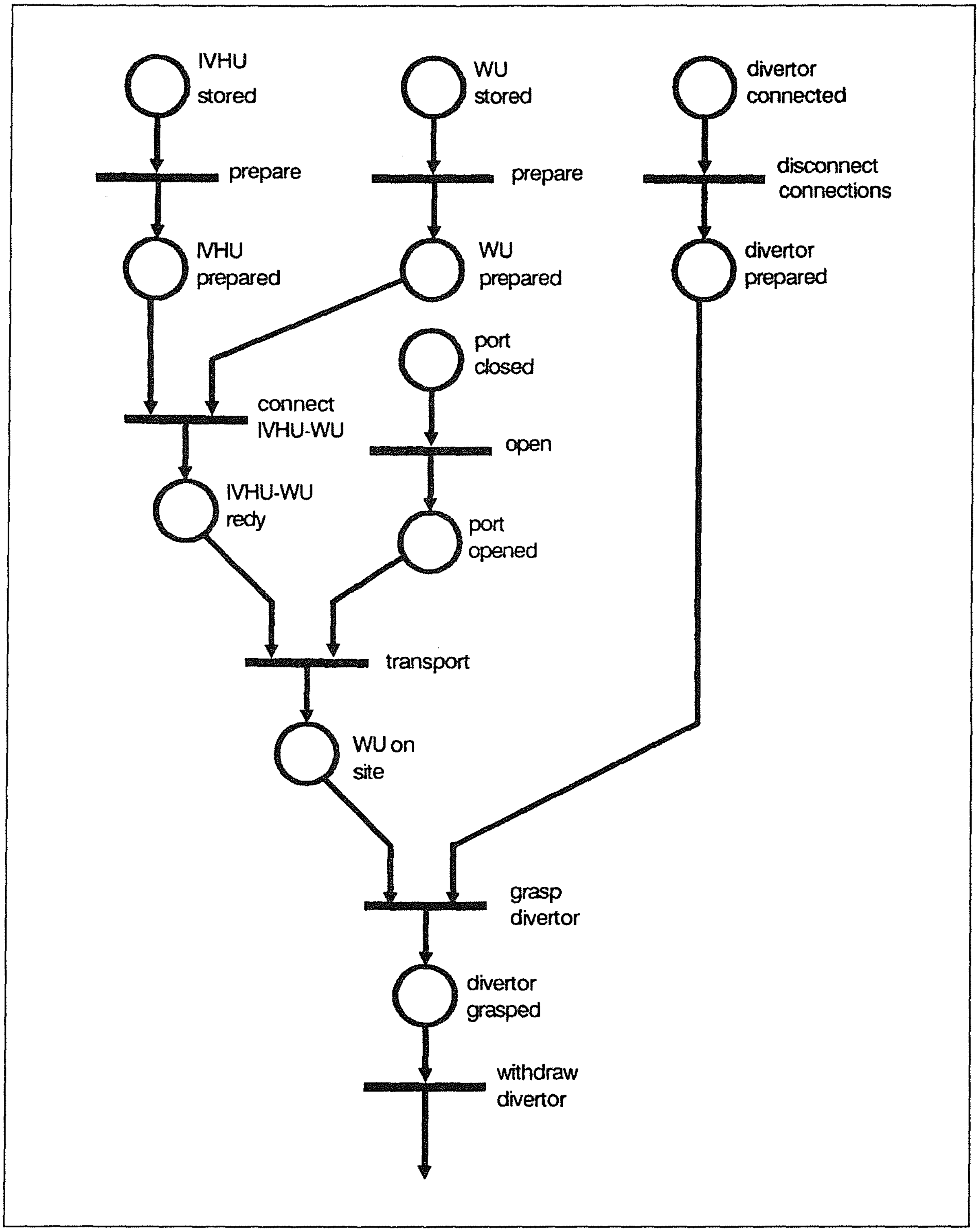

Figure 28. Example of an action net. These nets are used for high level planning and programming including especially the actions of the operator and the whole functionality of the control system. True state descriptions will be marked by a point in a circle (by tokens). The token flow through the structure represents the progress of work.

- functions DB containing the problem specific functional models

- attachment of the NRWS to a RH-area control system
- configuration, parametrization of the RH-area control system
- Installation of connections to related NRWS which have to collaborate

The operator should be able to set all parameters of the control system (perhaps under special restrictions) to adapt the system to a changed environment.

17.8 Communication

Direct verbal communication between operator teams should be completed by formalized communication via the NRWS communications module providing a special message service. This system should be used for organizing the cooperation of teams working at one major task. The message service provides

- message skeleton file,
- message skeleton index,
- message skeleton texts with embedded variables,
- set of standard messages,
- message management including
  - message tracing,
  - message journalling (logging).

The usage of this system improves the quality of messages to the user by making them more consistent and informative. Additionally it has the advantage of enabling basic surveillance of operator actions by the system by monitoring messages and their receipt. One special component of this computerized communication system is the large display visible for all teams. This kind of communication is well established in air traffic control, and, concerning the computer support, by general mailing systems. It should be a basic service in the NCS as well.

Of course, this communications medium can and should not replace verbal communication by head-phones or directly.

17.9 Commissioning

Experiences at JET have shown, that high level support systems like for example the spatial simulation system may be used in commissioning and testing RH equipment. The usage of the basic NRWS modules for this special task demands suitable subsystems and a special man-machine interface (a special window) which is tailored to this task. In the simplest case, the NRWS may be used as a recording system, e.g. recording a motion path of a transporter and other device measurements. The motion path, for example, afterwards may be displayed in the motion environment to help the operator in judging the behaviour of the device.

17.10 Basic Modules

These operator task specific functional modules discussed so far are based on three general modules:

- spatial simulator,
- procedure simulator,
- functional simulator.

Each of these simulators models the reality under a special aspect.

17.10.1 Spatial Simulator

Spatial simulation is based on a geometric/kinematic model of the equipment and the environment. These models are derived from the design data of the devices available on CAD-systems (Figure 29 on page 88). The basic design data is processed (manually) for the generation of the models. This process is not trivial, because the purpose of the needed model is quite another than that of the basic CAD data. To facilitate this model generation in a prototypic implementation on the KfK-CAD-system the ROBOT software [63]was developed which supports the generation of the kinematic relations and the generation of the model hierarchy needed to allow for intelligent model presentation (work phase adaption). To enable the model transfer between different CAD-systems and NRWSs the CAD*I data format is used for the prototypic implementation.

The prototype of such a spatial simulator is the KISMET system [64]which will be used for the JET-TARM control. The predecessor of KISMET is GBsim [65] developed and tested for the JET-BOOM control.

Basic features of the data structure of the simulator are

- kinematic description of RH equipment
- hierarchically organized description of equipment and environment (plant)
- parametric geometric elements (elements with variable geometry, e.g. crane ropes: planned)
- auxiliary geometric elements like for example frames representing local coordinate systems supporting manipulation of the data base

The spatial simulator is the basis for spatial monitoring, spatial guidance, motion planning and programming and for training of manual motion control. The model is updated continuously by signals (messages) from the equipment during the execution phase. During simulations the model update is done by the simulation subsystem by interpreting motion programs. Motion programs may be downloaded to the RH-area control system for execution.

A collision detection submodule is available for monitoring and support of motion programming.

A general message processor makes functions of the simulator available to other NRWS modules.

17.10.2 Procedure Simulator

On the highest level the maintenance task is described by maintenance procedures, sequences or nets of actions. The start of an action normally is restricted by specific conditions which must be fulfilled. Modelling of maintenance on a high level is therefore best done by using a net of actions and conditions, for example by PETRI-nets. To support the generation of maintenance procedures an editor is provided (Figure 30 on page 90). The generated procedures may be simulated and presented graphically to the planner. During the execution phase the procedure simulator is also used for procedure performance monitoring and as a basis for the advisory module. Activating an action on the procedure simulator means for example to advice the operator to do something or to start a motion procedure on the RH-area control system. Synchronization is done via messages between the different modules of the control system.

Comparing the procedure network with reality guarantees the correct performance of the planned maintenance (monitoring). Guidance for the operator is derived by generat-

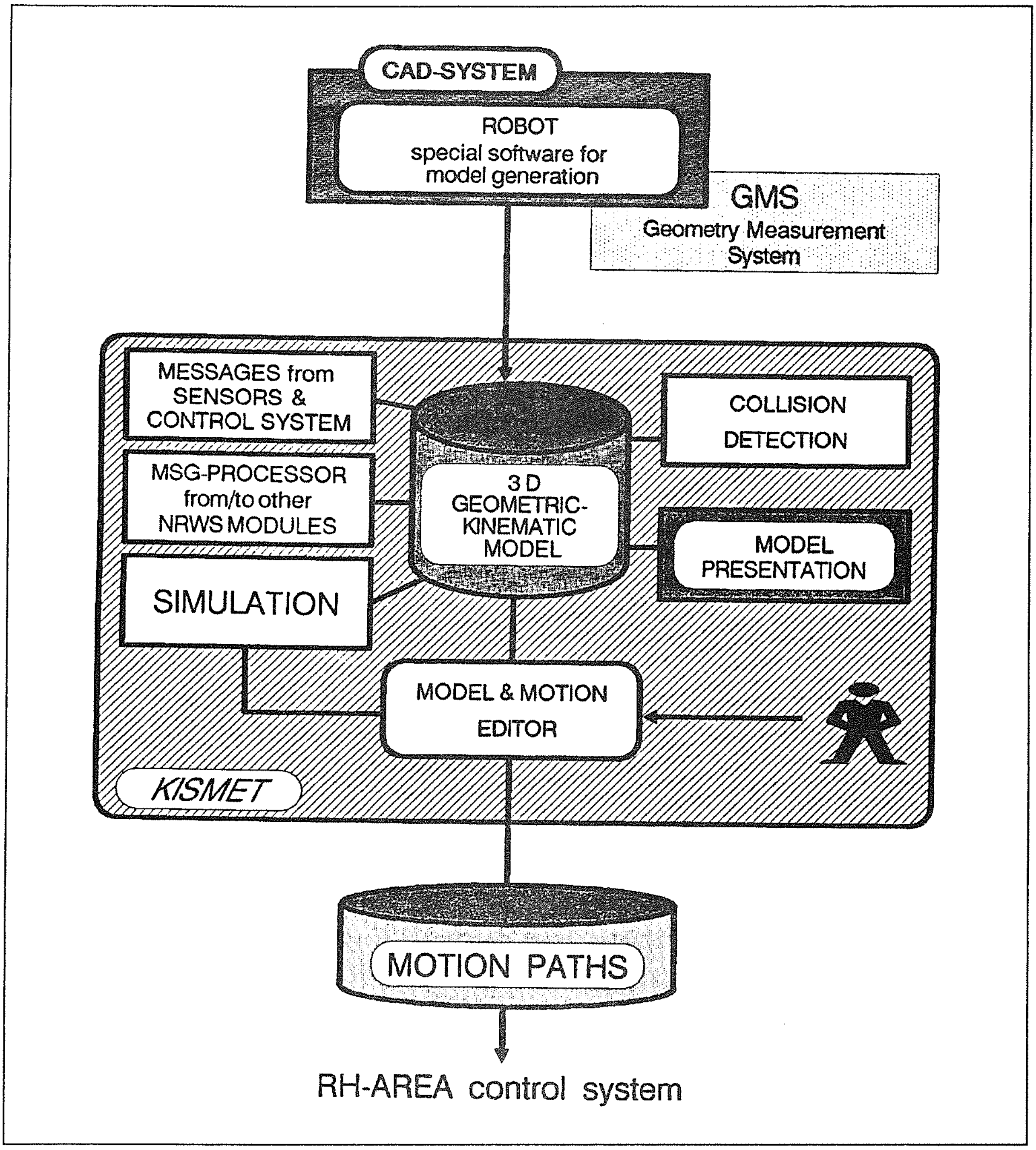

Figure 29. Architecture and usage of spatial simulator. The central 3D geometric/kinematic model of the equipment and the working environment is developed on a CAD system supported by special modelling software (ROBOT) and a computerized geometry measurement system (GMS) for model consistency checks. During execution of maintenance work the model is continuously updated by messages from the control system and sensors (e.g. joint angles). In the planning phase the operator may edit the models and motion paths for simulations. In both phases a collision detection is available. Developed motion paths may be stored or sent to the control system for execution or storage.

ing advice for the operator from the actions in the net. The advancement is dependent on the message from the operator signalling completion of an actual subtask. In some cases this information may be derivable from signals in the control system.

The basic elements of the procedure net data structure are actions (e.g. gripping, welding, drilling, screwing) and conditions (e.g. welding machine available, bolt fixed). These basic elements are connected by arcs to form a graph which represents the procedure (Figure 28 on page 85). The procedures (graphs) may be analysed whether basic features of the structure are fulfilled and the developed procedure is executable.

Simulation means to go through the procedure by marking step by step the states of the maintenance process modelled. The procedures are graphically presented as graphs with annotations. The basic data structure allows for a hierarchical modelling of the maintenance process. This means that a subprocedure, presented as a single structure object can be modelled in more detail on a lower level. The simulation of the procedures may be connected to the simulation of related motions of the equipment and to the simulation of the related functions. In this case the procedural simulation controls the other simulations for a complete presentation of the whole maintenance task.

A general message processor makes available all functions of the simulator to other NRWS modules.

17.10.3 Functional Simulator

A functional model is based on sets of values describing devices, sub-devices, or special functions or states of the equipment as for example force-torque data, proximity data, velocities, temperatures, electric currents or voltages etc.. The whole RH system is separated into functions represented by

- sets of values,
- limits of values,
- relations between these values,
- limits for derived values and trends of changes,
- pictures for problem suited function presentation like
  - mimics.
  - bar graphs,
  - curves,
  - process flow graphs,
  - topographies.

The whole RH equipment is represented by a hierarchical set of schematics going from an abstract representation stepwise to more detailed representations. the visible schematics are beeing updated continuously with changing equipment parameters. The operator has available navigation aids to walk through the hierarchy as needed. In an advanced version the system should provide the best selection of schematics in dependency of of the phase of work automatically.

A simple example is shown in Figure 44 on page 103. This set of subwindows support the operator in monitoring a cooling circuit, a welding machine, a group of motors, a gripper, and divertor and antenna installation. These functional representations are updated by the "process" or in a simulation phase by a simulation software.

The basic simulator (Figure 31 on page 90) provides a set of general value presentation techniques (simulated meters, tables bar charts, diagrams) and a set of task specific process abstractions for process parameter presentation (e.g. flow sheets with annotated values).

The model (set of values and relations) is continuously updated by messages (MSGs) coming from the equipment (via RH-area control system) or directly from the RH-area control system.

The basic automatic monitoring function provided directly by the simulator is a monitor surveying all incoming values based on given limits or trend characteristics.

A general message processor makes available all functions of the simulator to other NRWS modules.

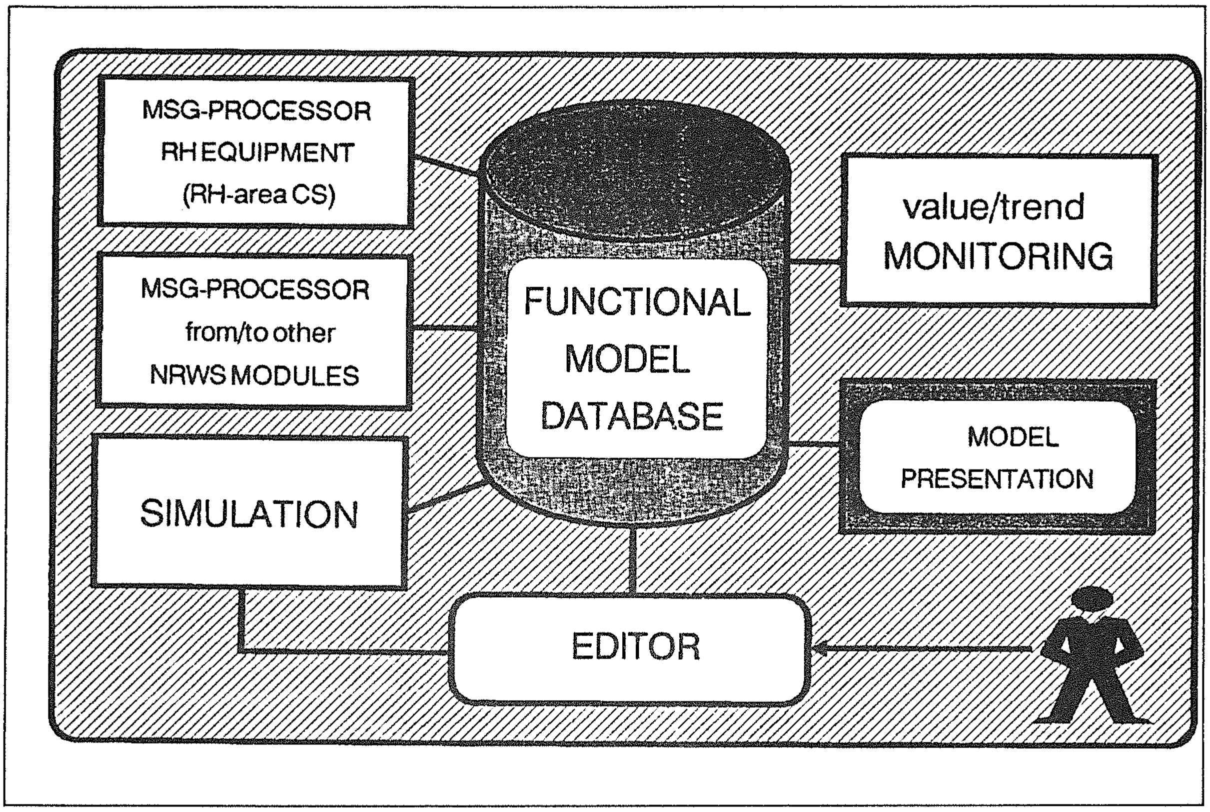

Figure 31. Architecture and usage of functional simulator. For synchronization of the simulator and the control system a special interface is provided, for communication with related NRWS modules (e.g. spatial simulator) a separate interface is available. The system provides modules for value and trend monitoring. The development of functional models is supported by an editor.

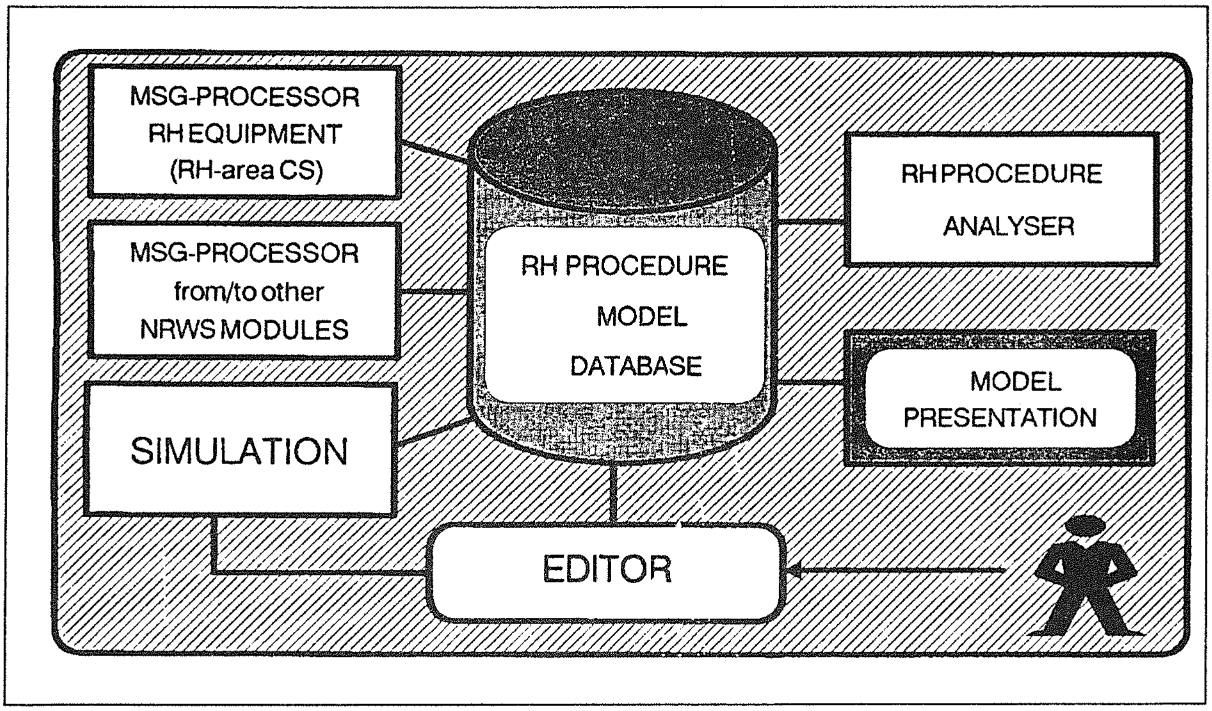

Figure 30. Architecture and usage of procedure simulator. For synchronization of the simulator and the control system a special interface is provided, for communication with related NRWS modules (e.g. spatial simulator) a separate interface is available. Procedures may be analysed by various modules in the planning phase and monitored during execution. Development of the procedure models is supported by a special editor.

18.0 NRWS Architecture

To provide easy maintenance, easy extendability, and easy usability the NRWS is designed highly modular concerning both, hardware and software. This modularity facilitates also the implementation because the different subsystems may be developed independently.

18.1 Software Architecture

The functional modules of the NRWS are shown in Figure 32. The basic or kernel modules are simulation systems working on three different world models:

- spatial simulator modelling the spatial relationships in remote maintenance,
- procedure simulator modelling the RH procedures,
- functional simulator modelling general functionalities.

On the basis of these three simulators a group of operator task dependent support modules are implemented which realize the functions of the NRWS presented and discussed in 17.0, "NRWS Functionality" on page 75. These independent problem class specific support modules are:

- Planning & programming
- Integrated viewing
- Monitoring
- Guidance
- Training
- Communication & Dialog
- Configuration
- Logging
- Commissioning & Testing

Each of these modules is represented for the operator through a separate window (window set) which is discussed in 19.1.2, "NRWS-Windows" on page 100.

For some of these modules especially planning, guidance, and monitoring advanced software techniques seem to be very promising. These techniques are generally labeled by "Knowledge Based Techniques" and more specifically as "Expert Systems". For the special context of remote handling the applicability should be investigated, in some other fields the usability is already proven.

Knowledge based techniques are especially designed for applications characterized by

- a high complexity of the data structures needed to describe the reality (much higher than usual in databases),
- a high degree of uncertainty (e.g. "what should be done in a special situation" or "what is the reason for a malfunction").

Knowledge based systems are designed for tackling problems with a certain degree of indetermination which tend to result in a combinatorial explosion which forbids a complete or exact solution.

A central feature of knowledge based systems is to derive implicit knowledge out of explicit knowledge (entries in databases) to make it explicit. Those algorithms transforming implicit knowledge into explicit knowledge are called inference algorithms. The solution of a task, if resolvable at all, is already implicitly existing and has to be made explicit.

Software systems using these knowledge based techniques for special tasks as diagnosis, planning, decision support, or supervision are called expert systems. These expert systems as well as the knowledge based techniques only run effectively, according to the state of the art, on special workstations (see: 18.2, "Hardware Architecture").

The introduction of these advanced support modules based on ″knowledge″ is planned to be done stepwise:

1. Implementation of problem tailored knowledge bases and manual usage by the operator (inference by operator),

2. Implementation of expert systems using these knowledge bases running in an advisory mode.

18.2 Hardware Architecture

To get high flexibility in both, development and operation, the NRWS is not implemented on one computer but it will be implemented as a connection of general purpose or special purpose engineering workstations. The number and kind of workstations actually connected to the NRWS depends on the phase of maintenance work. The integration of the NRWS parts to the actual workstation of the operator is done via the RH-bus (Ethernet, TCP/IP) using the X-Window system which allows for an arrangement of working windows as the operator needs it. For data exchange between the computers a special data transfer format (TBD) is used.

For a fully equiped NRWS three types of workstations (WS) are used:

- High performance graphics workstation (GR-WS)
- Knowledge-based workstation (KB-WS)
- General purpose engineering workstation (GP-WS)

The KB-WS and the GP-WS may be of the same kind (e.g. SUN4). The GR-WS is needed to provide real-time spatial simulation, the procedural and functional simulation is partly based on knowledge-based techniques which are only effectively runnable on special hardware. Functional modules without special bottlenecks will be implemented on GP-WS as well as the operational interfaces of the RH area control systems (19.3.2, "Operating Interface" on page 105).

As far as possible the number of different types workstations should be minimized, but according to the actual state of the art, two different types are needed (IRIS, SUN).

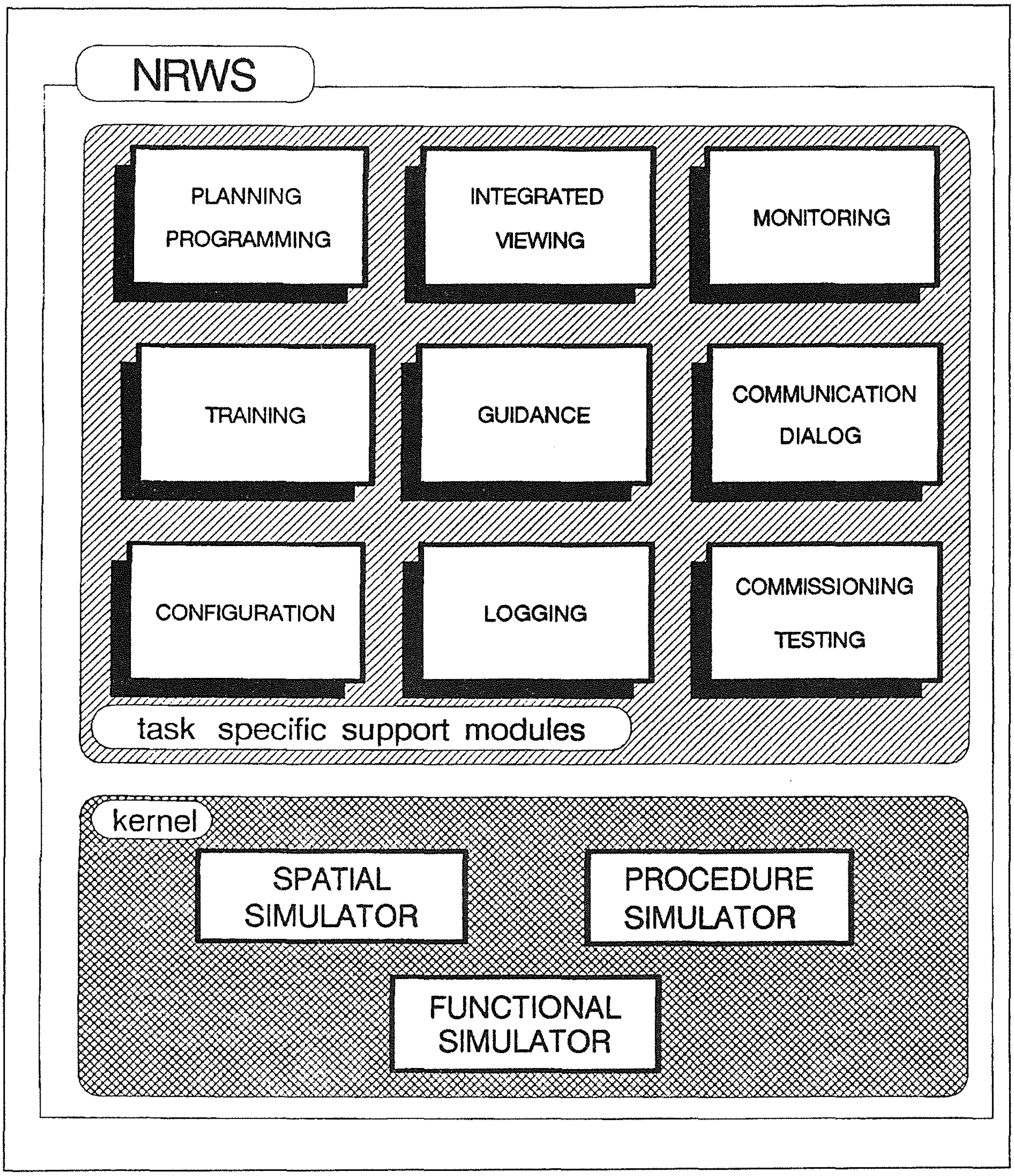

Figure 32. Functional modules of NRWS. The task specific support modules are using the kernel modules which provide the basic functions of simulation, monitoring, editing, and presentation.

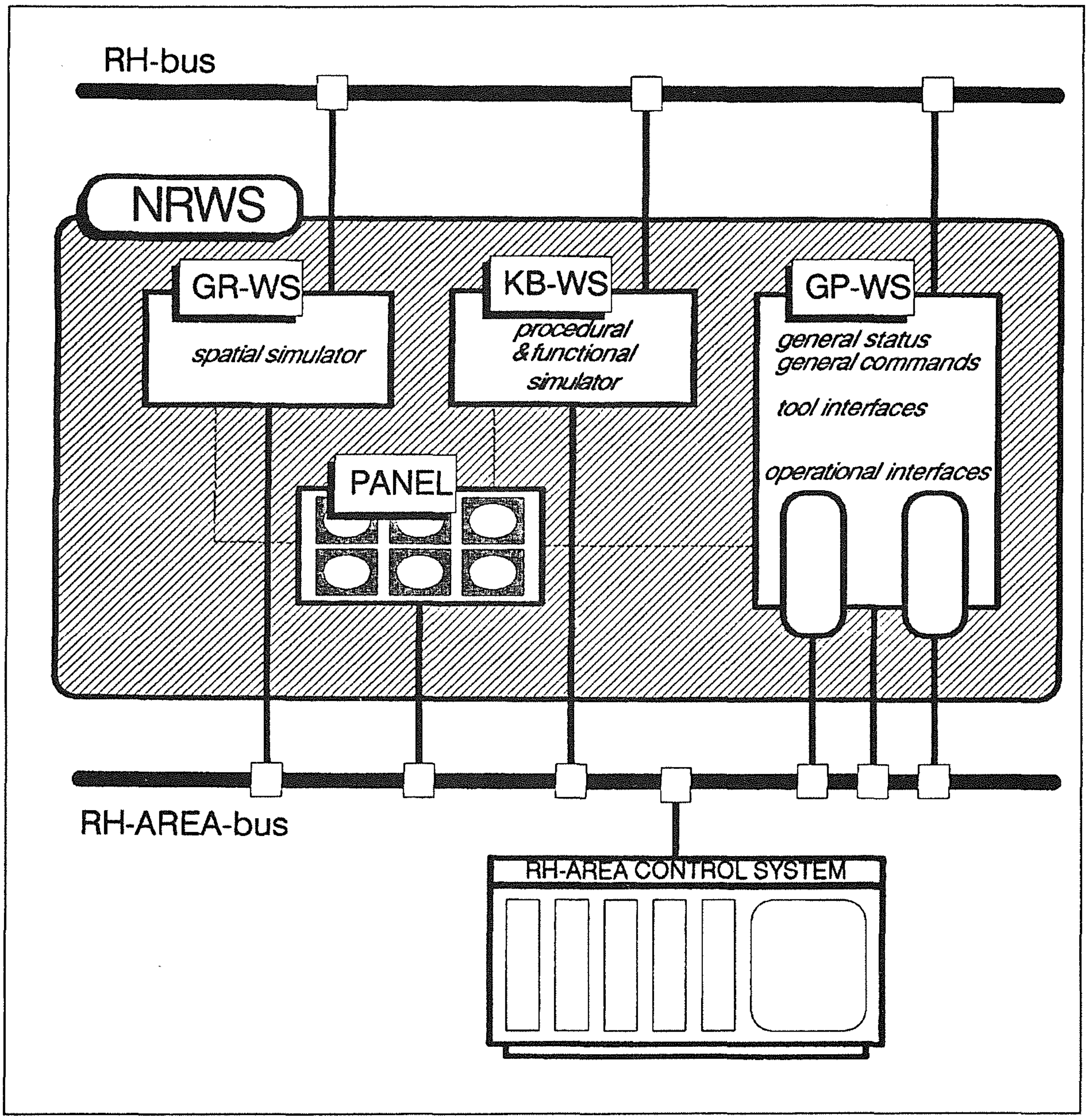

Figure 33. NRWS hardware architecture. Integration of workstations to the NRWS is done by using suitable software providing hardware independence (X-windows). GR-WS: Graphic Workstation, GP-WS: General Purpose Engineering Workstation, KB-WS: Knowledge-based Workstation, PANEL: Input devices and display screens integrated by X-window technique (Client). This integration of a panel is not state of the art.

19.0 NRWS Interfaces

The NRWS is integrated in its environment by a group of interfaces shown in Figure 34. The main interfaces are those for communication with the operator and with the attached RH-area control system. They are discussed in greater detail. The interface to the central utilities provides access to databases. The NRWS are connectable via a special interface (e.g. synchronization of IVHU-work and auxiliary transporter) which is used in cases of collaboration. The definition of internal interfaces is important for guaranteeing the extendability and modularity of the NRWS. A special internal interface is an interface to configuration files in a central RH-database. Configuration files allow for an easy software reconfiguration if the NRWS is attached to new tasks or other RH-area control systems.

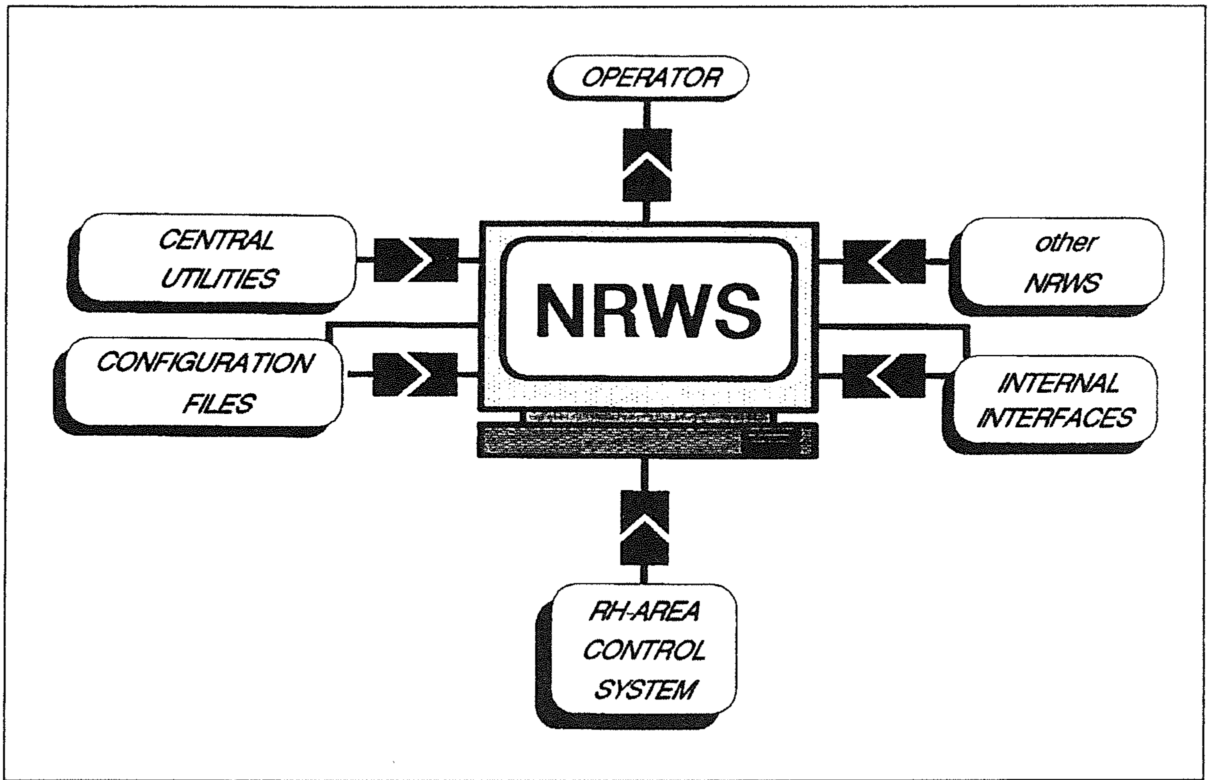

Figure 34. Interfaces of NRWS

19.1 Operator Interface

The operator interface is represented by the physical arrangement of input and output devices in an operating panel. The arrangement and the selection of these devices depends on the type of work which has to be controlled. The following classes of NRWS operator interfaces (NRWS panels, station) are defined:

1. Master-slave manipulator control NRWS-panel
2. Transporter control NRWS-panel
    - In-vessel handling unit
    - Blanket handling unit
    - others
3. Tool control NRWS-panel
    - welding
    - others

4. Inspection NRWS-panel

- leak detection
- in-vessel tile inspection
- others

5. Supervisor NRWS-panel

The first two panels are panels for teams of two operators: an executing operator, controlling the motion manually and doing contact work; and a support operator, controlling viewing equipment and the computer aided support tools like simulation etc. The skill of the first operator has to be mechanical dexterity the skills of the support operator have their accent in the area of computer usage.

Tool control, inspection and control room supervision are single person places.

The number of places at each panel are places for the basic crew, it should be possible to place at least one further person.

The basic information arrangement is done by panel layout, on the next level of detail the information is arranged by windows on the various displays. The layout of the main windows is introduced in the second subchapter.

19.1.1 NRWS-Panels

The following panel descriptions are only first proposals to show the basic functional requirements. A thorough ergonomic layout is needed (20.0, "Future Work" on page 111). The mechanical and electrical layout of the panel allow for a easy rearrangement. The allocation of screens for a special purpose and the allocation of space on the screens is controlled by software using the configuration files. Rearrangements are easily done. The only restriction is the monitor type: windows may only be allocated to computer display screens, not to TV screens. This restriction may be canceled in the near future because graphics and TV may be intermixed.

The panel layout demands for special ergonomic research, the preliminary schematic panel layouts in this chapter are based on the use of standard industrial control panel as shown in Figure 35 on page 97. The purpose of this layout is to demonstrate the functional needs. The input devices shown in the schemas shall only demonstrate standard possibilities, ergonomic research has to evaluate which devices are best suited for a special task. A general goal is to minimize the number of input and output devices needed as far as possible and reasonable while providing the possibility of choosing a favourite device to the operator.

19.1.1.1 NRWS-Panel for Master-Slave Manipulator Control

The dominating tools for the manipulator operator are the master station and TV displays for obeying contact work. The central tool for the support operator is viewing control. This leads to a panel layout as shown in Figure 36 on page 98. Especially the spatial layout of the execution area of the panel is only shown schematically. In this case the spatial arrangement of the video screens has to be detailed. The shown panel arrangement should only represent the front screens which should be completed by screens positioned on a sphere sector. Repositioning of these screens is possible so that the screen arrangement may be done according to the actual work phase. Advice for the operator are given in a short form: the support operator will get complete advice. During the work the executing operator has the possibility of obeying a functional monitor for controlling some important functions of the manipulator (e.g. forces, currents). The supporting operator has access to the complete monitor. the main task of the support operator is camera control and provision of TV pictures for the main operator.

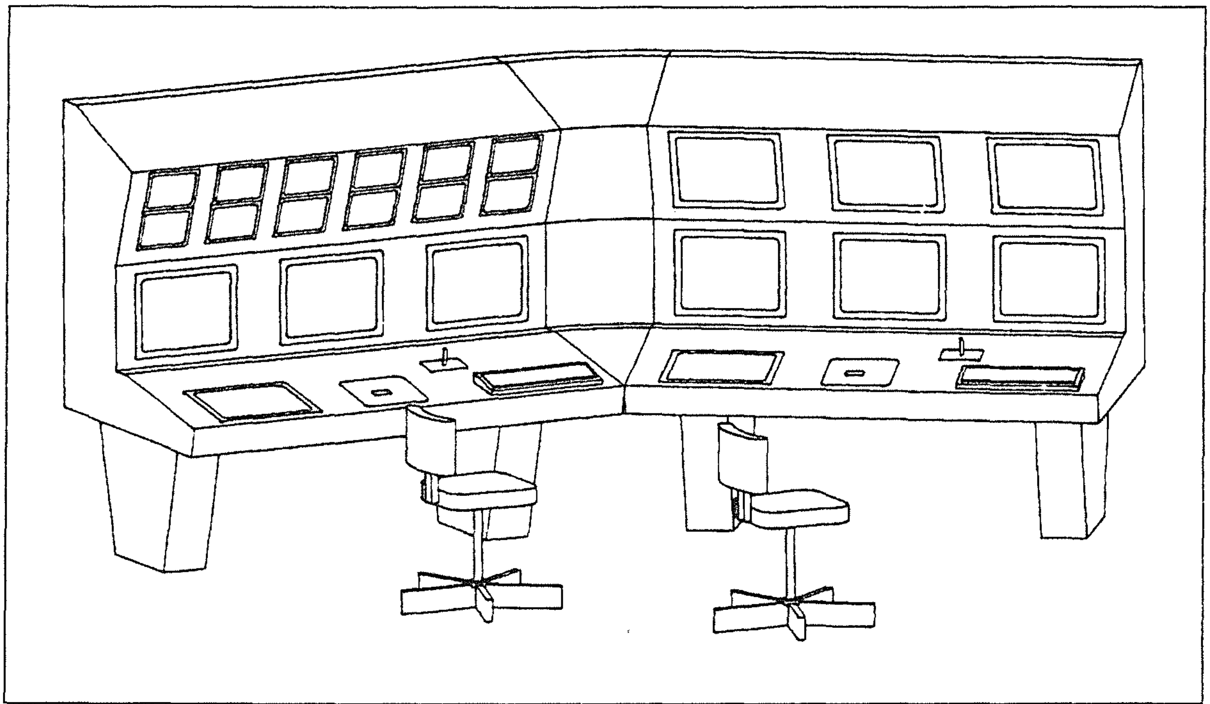

Figure 35. Standard industrial control room panel. The functional panel layout for the different types of panels is based on a standard industrially available panel. An ergonomic layout is still needed.

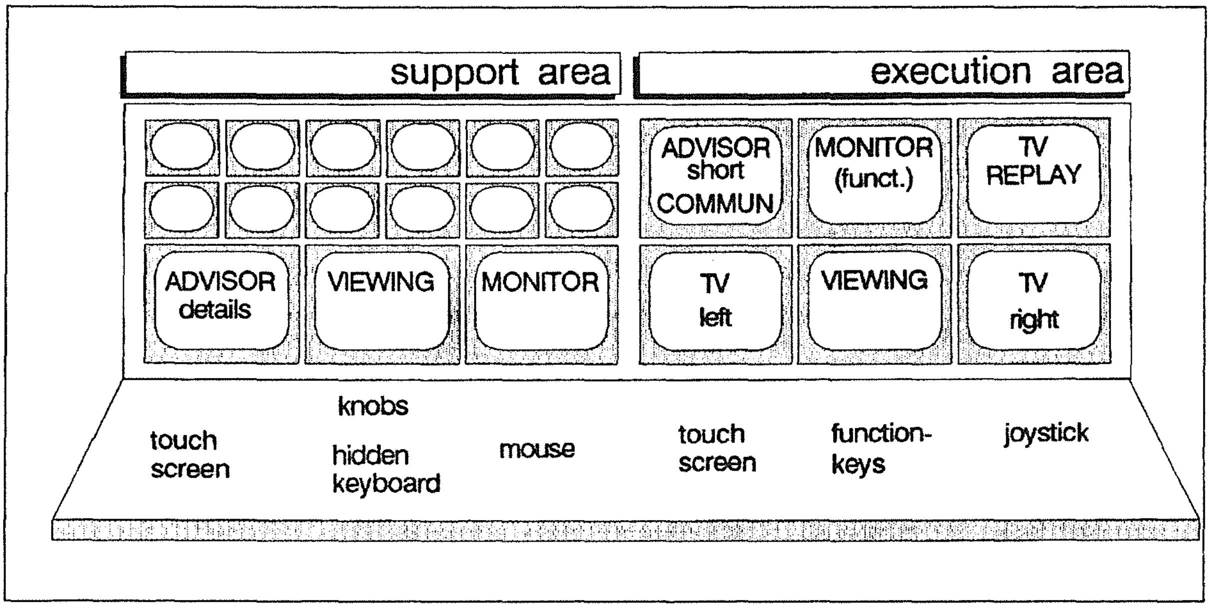

Figure 37. NRWS-panel for transporter & work unit control. The most important information for the executing operator controlling a work unit with a joystick are two TV screens and the VIEWING screen. The support operator controls the transporter by a joystick mainly via a VIEWING screen.

19.1.1.2 NRWS-Panel for Transporter Control

The work of controlling the transporters is also done by two operators, one controlling the motion, the other for supporting tasks like camera control and proper performance of the task (Figure 37). The central aid for the motion control operator is the graphic screen showing overviews, details, and special camera views on the VIEWING screen. In addition he has two TV screens for direct work support. For his general information he has the monitor display of important functions. Advice is presented to him in a short form. Complex control steps can be presented as TV replay or as simulations on the central VIEWING screen.

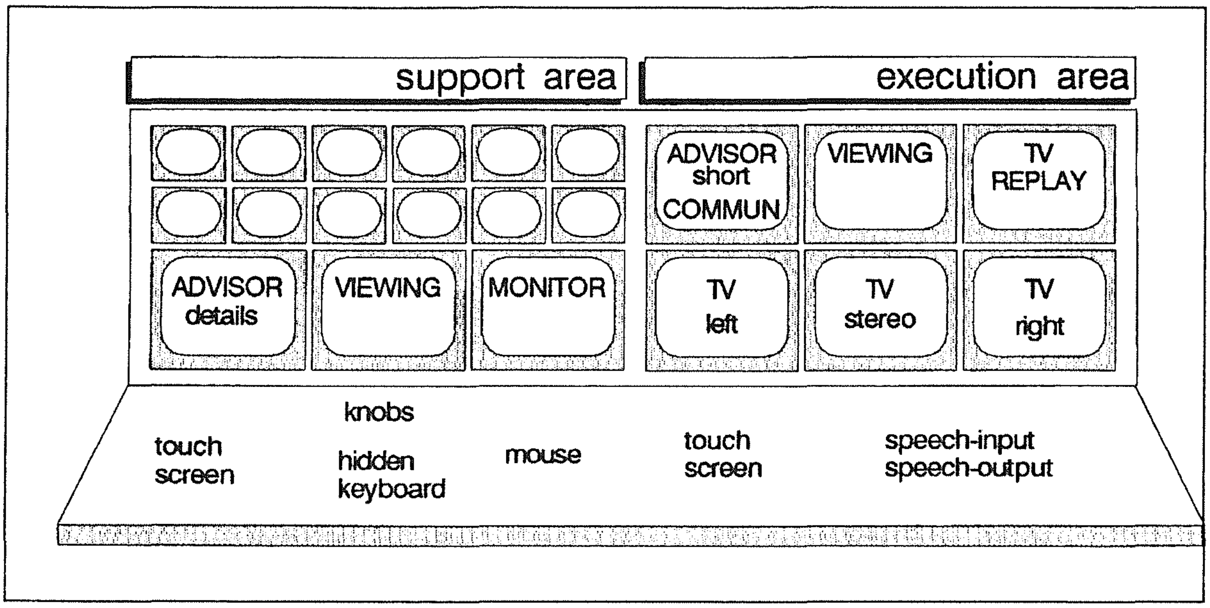

Figure 36. NRWS-panel for master-slave manipulator control. The executing operator (MSM operator) is mainly using speech input, the main displays for him are TV displays and the VIEWING display. The support (camera) operator is mainly using the VIEWING display.

19.1.1.3 NRWS-Panel for Tool Control

This activity is characterized by controlling a more or less automatic processes like for example a welding machine which means mainly supervising process parameters (Figure 38 on page 99). This can be done by one operator using three large TV screens for looking at details, one VIEWING screen for the overview and camera control, and two MONITOR screens for monitoring the diverse process parameters. He is guided through the task sequences by the complete advisor.

19.1.1.4 NRWS-Panel for Inspection

This task is done by two operators: the inspector and the transporter driver (Figure 39 on page 100). The speciality of the inspection work place is the provision of comparison aid like a slide projector and a special TV screen. These aids allow to compare actual pictures for example of surfaces with original, good quality pictures of the same scene.

19.1.1.5 NRWS-Panel for Supervision

The supervisor has to supervise all of the ongoing tasks and to guide the operators in abnormal situations (Figure 40 on page 99). He therefore has available four monitoring screens and two viewing screens. The two additional large TV screens are playing no central role. There is a COMMUNICATION screen (Figure 41 on page 99) which is used for formal communication with the operators. This communication is also supported by a three large (2m*2m) screens on which the supervisor can display information important for more than one team. The communication via the common screens is supported by a pointing device available to each team.

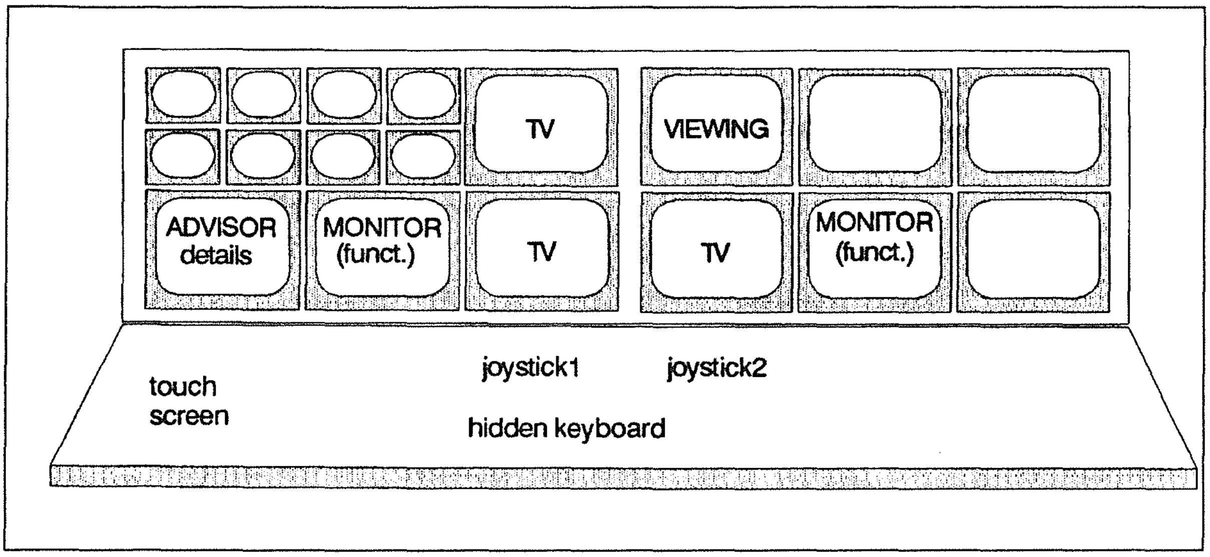

Figure 38. NRWS-panel for tool control. This panel is designed as a one operator place for controlling for example a welding machine.

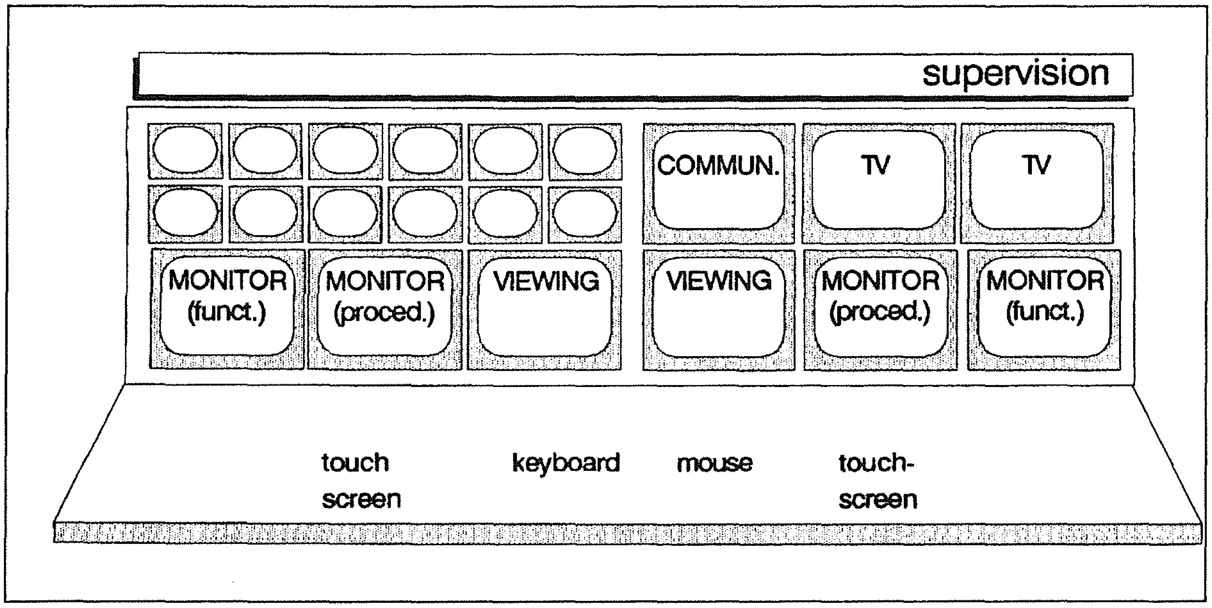

Figure 40. NRWS-panel for supervision. Supervision is mainly VIEWING (overview) and MONITORING

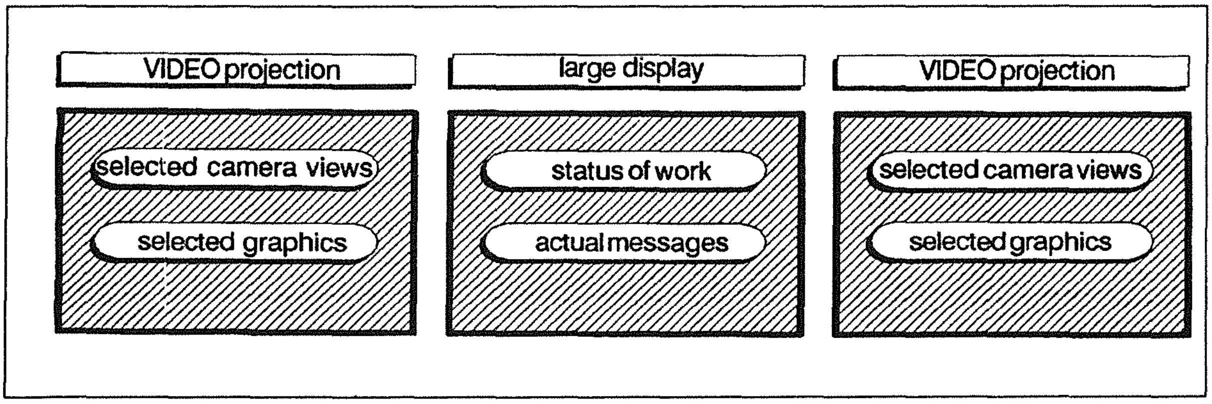

Figure 41. NRWS common screens. Directed by supervisor, cursors for each team (3*2m*2m)

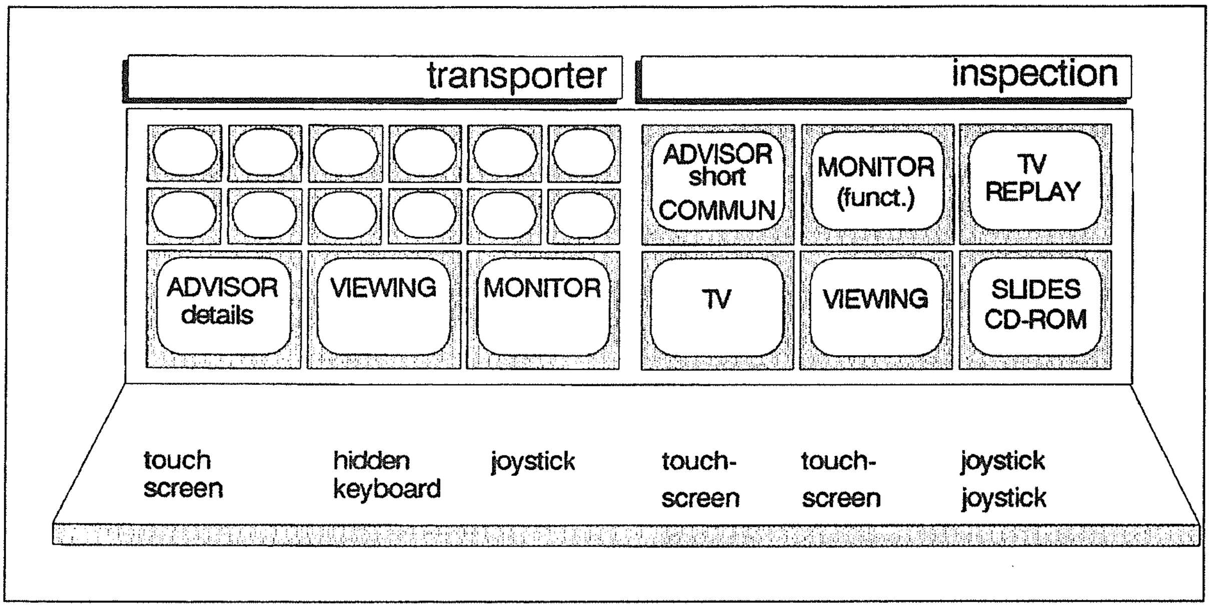

Figure 39. NRWS-panel for inspection. This is a two operator place (inspector and transporter driver) because both activities are needed more or less at the same time.

19.1.2 NRWS-Windows

This proposal for windows shall mainly demonstrate the possibilities and general appearance of the information. According to the standard used for implementation (X-windows) not all windows have to be seen as complete as designed, but it is always possible to iconize a window if it is currently not of interest.

The following window layouts mainly show the basic subwindows. Additional information called by special commands is displayed in special subwindows which overlay the basic ones. The set of windows presented below is not complete because only a general overview over basic features of the NRWS shall be given in this paper. A detailed design of the windows has to be done later.

19.1.2.1 Guidance Window

The operator guidance/advice window (Figure 42 on page 101) shows the sequence of actions the operator has to do in performing a task. This is presented as a graph showing also the intermediate states of the work and the conditions for execution of an action. The display of this graphic representation of the RH procedure can be given in more or less detail. As a short form of these advices in a special subwindow the previous action, the running action and the next action are displayed. These will be seen even if the graphical presentation will not be seen. With a group of commands the operator may demand help, explanations, and additional information concerning the state of the maintenance process. The operator may also ask for for a simulation of the next steps or a video, if available from previous work.

19.1.2.2 Viewing Window

The VIEWING window (Figure 43 on page 102) represents the window to the integrated viewing subsystem. Through this window the operator gets normally different graphic views of the scene (e.g. top view, side view) and if needed a detailed view in form of an included TV subwindow. The control of the cameras is integrated and done through the camera control subwindow.

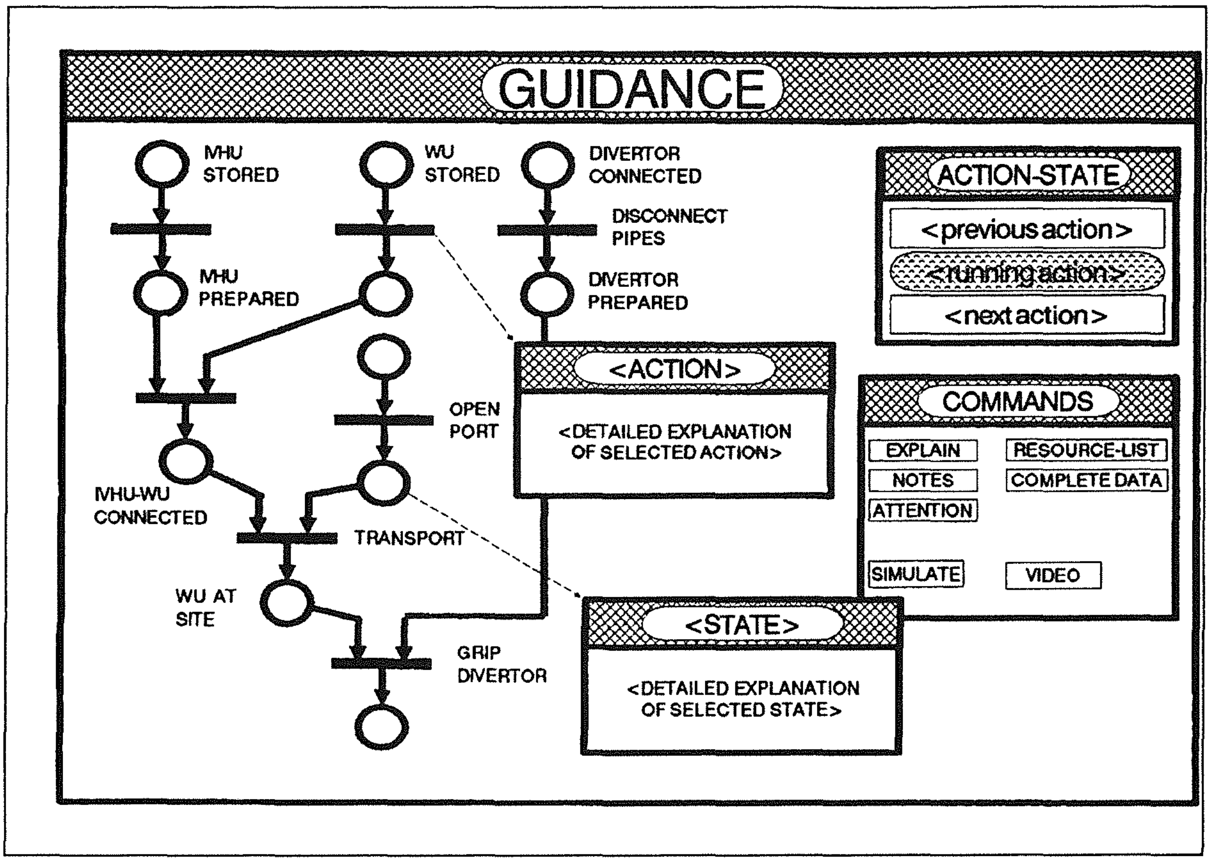

Figure 42. Guidance window. As basic information the window shows the procedure as an action net. Subwindows allow for displaying of detailed information about the procedure elements, the actual state of the task, and the actually available commands, dedicated to guidance.

19.1.2.3 Monitoring Window

According to the three model types available in the NRWS monitoring covers three areas. Spatial monitoring plays a special role and is covered by the integrated viewing subsystem and its window. Function and procedure oriented monitoring is accessible by windows presented in this chapter.

Functional Monitoring: To support the operator in monitoring the various subsystems and RH devices are presented in a functional (Figure 44 on page 103) manner by diverse types of two-dimensional graphics as:

- line graphs, curves
- area, band, or surface charts,
- bar graphs, column charts, histograms
- stacked or segmented bars or columns
- pie charts
- simulated meters
- star, circular, or pattern charts
- flow graphs, status graphs
- electrical schematics.

All this graphics or tables are dynamic. These techniques of functional presentation are standard in power station control rooms. The specific characteristic in the NRWS envi-

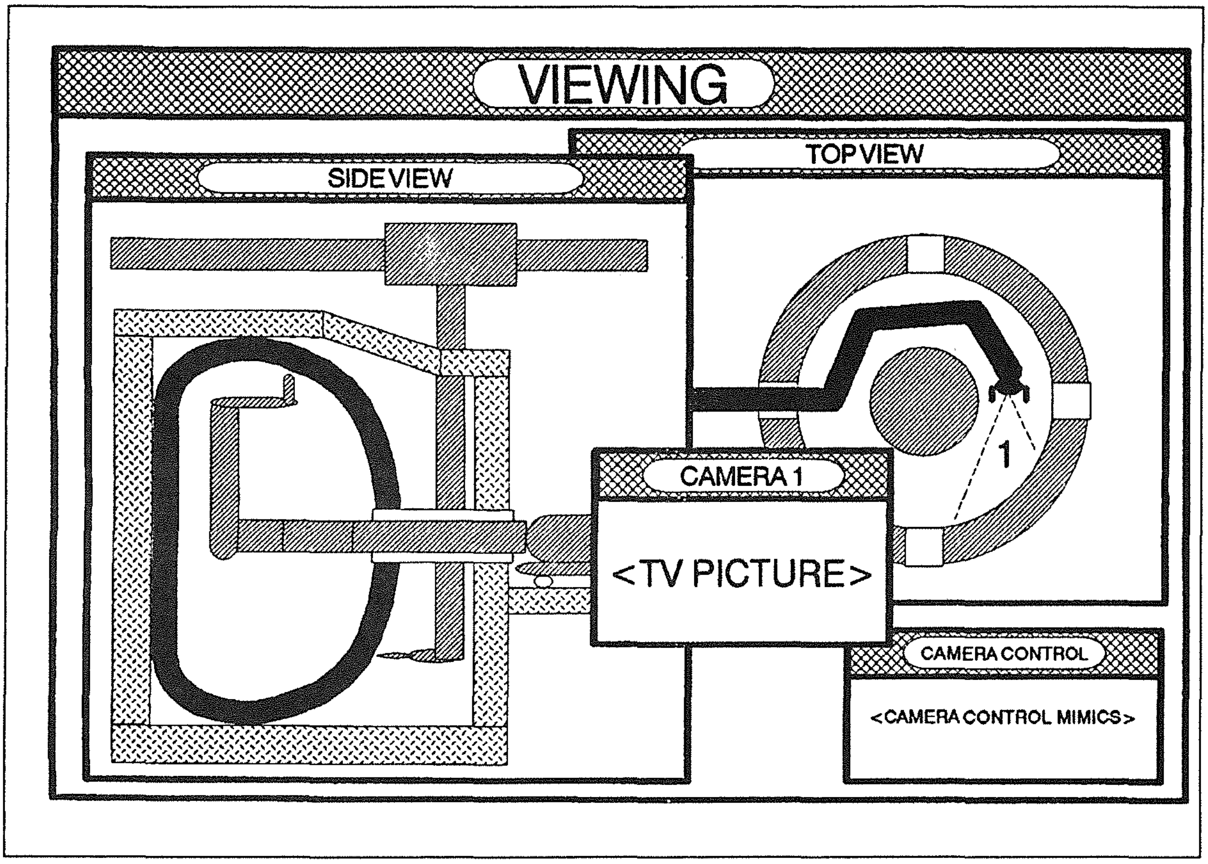

Figure 43. Viewing window. Support the operator in scene surveillance. The example shows the side and top view of a torus. A special window overlays the the picture of the camera 1 onto the animated graphics. In the top view the viewing angle of the camera is marked. A further subwindow provides a camera control interface.

ronment the kind of implementation on workstations. The subwindows may be opened automatically by the automatic monitors running in the background.

Procedure Monitoring: The basic window for procedure monitoring (Figure 45 on page 104) is very similar to the advisory window but the focus in this context is the presentation of the status of the work not so much the actions. Therefore many subwindows are defined for controlling the actual status of the work. Alarms are produced by the automatic monitor if the ongoing work differs from the plan.

19.1.2.4 Planning/Programming Window

This window is tailored to the needs of data and command entry for procedure model and motion generation combined with simulation on the procedure simulator as well as on the spatial simulator. In addition, access to the central databases for RH equipment, spatial models, task logs, and the resource manager is provided (19.6, "Central Utilities Interface" on page 106).

19.1.2.5 Training Window

This window serves to coordinate all functions needed for training maintenance tasks. These are (Figure 32 on page 93): guidance, integrated viewing, monitoring, simulation.

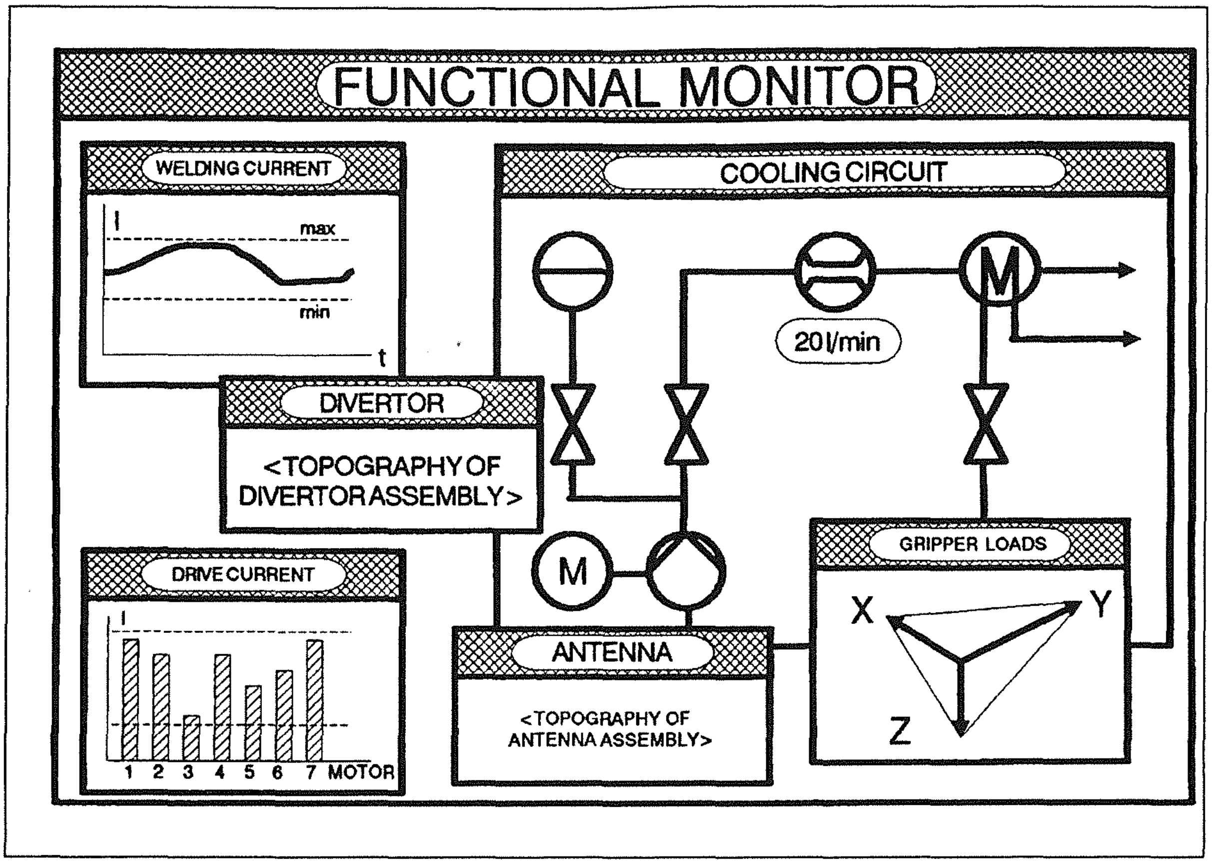

Figure 44. Functional monitor window. The examples shown support the operator in monitoring a welding machine, several motors, a cooling circuit, and gripper loads. Further sub-windows provide topographic information (mimics) about the divertor and/or antenna assembly state.

19.1.2.6 Communication Window

This window may be mainly iconized. If messages arrive, the window will be opened automatically to direct the operator's attention to the massage. For sending messages the system provides an address list, predefined standard messages (which will be selected according to the actual task phase), and standard message forms which can easily be filled out.

19.2 Interface to other NRWS

This interface serves for coordinating tasks done at different workstations. The messages have to be defined.

19.3 RH-Area Control System Interface

For integration into the control system hierarchy a RH-area control system has to provide two types of logical interface:

- A general interface, allowing access to the complete functionality of the RH-area control system and
- an operating interface representing a man-machine interface to the basic operations of the RH-area equipment.

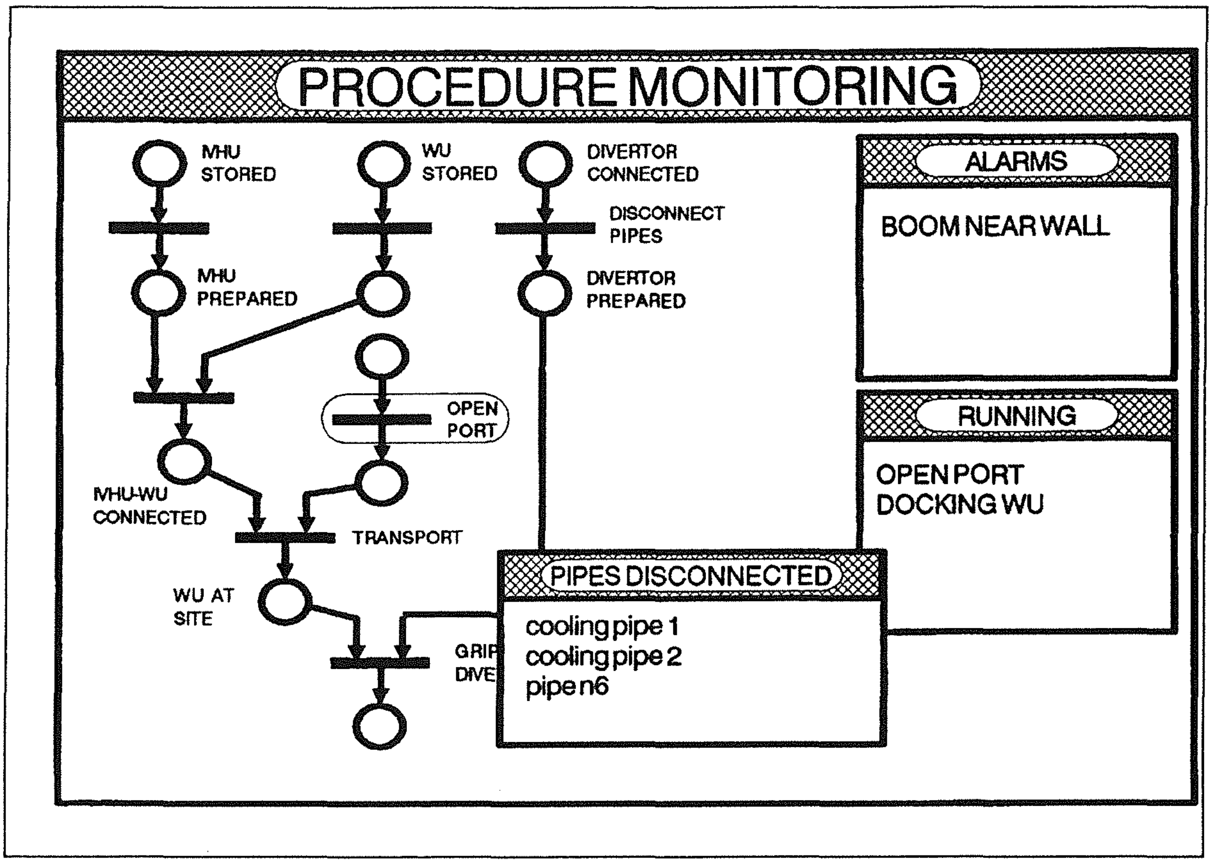

Figure 45. Procedure monitor window. The actual state of e.g. divertor exchange is presented by an action net. Subwindows provide information about a piping subtask, running subtasks, and alarms (warnings).

19.3.1 General Interface

This interface provides the full functionality of the RH-area control system and access to all data of the equipment and the controllers. The general functions of the RH-area control system are:

- basic equipment control (non-motion)
- basic motion control (closed loop control)
- single command execution (manual mode)
- program execution (automatic mode)
- on-line teach/repeat
- backtracking
- operator support functions (e.g. jigs)
- signalling of status changes to NRWS
- setting of control system parameters by NRWS
- logging

The interface has to be defined in terms of messages controlling this functionality and delivering status values. The basic framework for this interface is the ISO/DIS Manufacturing Message Specification [66]. For the description of motion (programming of the manipulators and transporters) IRDATA [67] should be used. A more detailed description of such an interface is found in [60] for the special case of the IVHU control system. The commands of the related JET-TARM control system are found in Appendix C, "TARM Control System Command List" on page 137.

19.3.2 Operating Interface

Concerning the variety of different special tools which have to be controlled it is hard to imagine that all the operating interfaces of the various control systems can be generalized such that a configuration process is able to adapt the NRWS to the very special requirements. Therefore the NRWS has a special interface (same kind of a "drawer section" to accommodate the so called "Operating Interface Module" (OIF_M) representing user interfaces for special RH machines (e.g. welding tool, IVHU) (Figure 46 on page 106)[4] . An example of These modules demand only for the input/output facilities of the NRWS and its computing power. Basically no communication between this module and the other NRWS support module is defined. To guarantee this integration those modules have to use the following internal NRWS interfaces (according to state of the art, but see Appendix A, "Requirements Definition Document for NRWS" on page 117)

- X-WINDOW as input/output device interface
- UNIX and UNIX libraries
- C as implementation language

Obeying these boundary conditions it is possible to run a special user interface to a special control system on the NRWS together with the basic functions of the NRWS (Figure 46 on page 106). This is due to the multitasking and windowing techniques. For implementation and test purposes those modules may be run on an independent computer in an environment providing the same boundaries.

Working with the standard functions of the NRWS the operator is able to call such an integrated special module and to allocate a special window at the screen for CS operating using the NRWS window manager.

This type of interface is defined for attachment to control systems not running X-window, which may be the case for simple control systems. If the control system is running the X-window system, its operating interface should or may be implemented on the RH-area control system itself (e.g. the RH-area controller (Figure 20 on page 70) using X-window (OIF_W). In this case, the NRWS can simply open a window communicating with this control system operating interface. This interface is called "Operating Interface Window" (OIF_W).

This kind of integration of special functions are the loosest kind of integrating functions into the NRWS.

19.4 Internal Interfaces

Internal interfaces are interfaces between NRWS modules and interfaces between those modules and the operating system. These interfaces for NRWS integration and communication in the NRWS between modules have to be defined in detail, they are mainly defined by using a UNIX environment.

19.5 Configuration Files

The configuration of the NRWS for a special application or special work phases is done by the operator through the configuration module. The result of this work are the configuration files containing the configuration data as ASCII strings. The configuration file language has to be defined. It should be described, to allow for configuration file generation or modification also using a text editor.

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[4] An example for such an operating interface module is the JET-TARM handbox software, actually runnable on a PC.

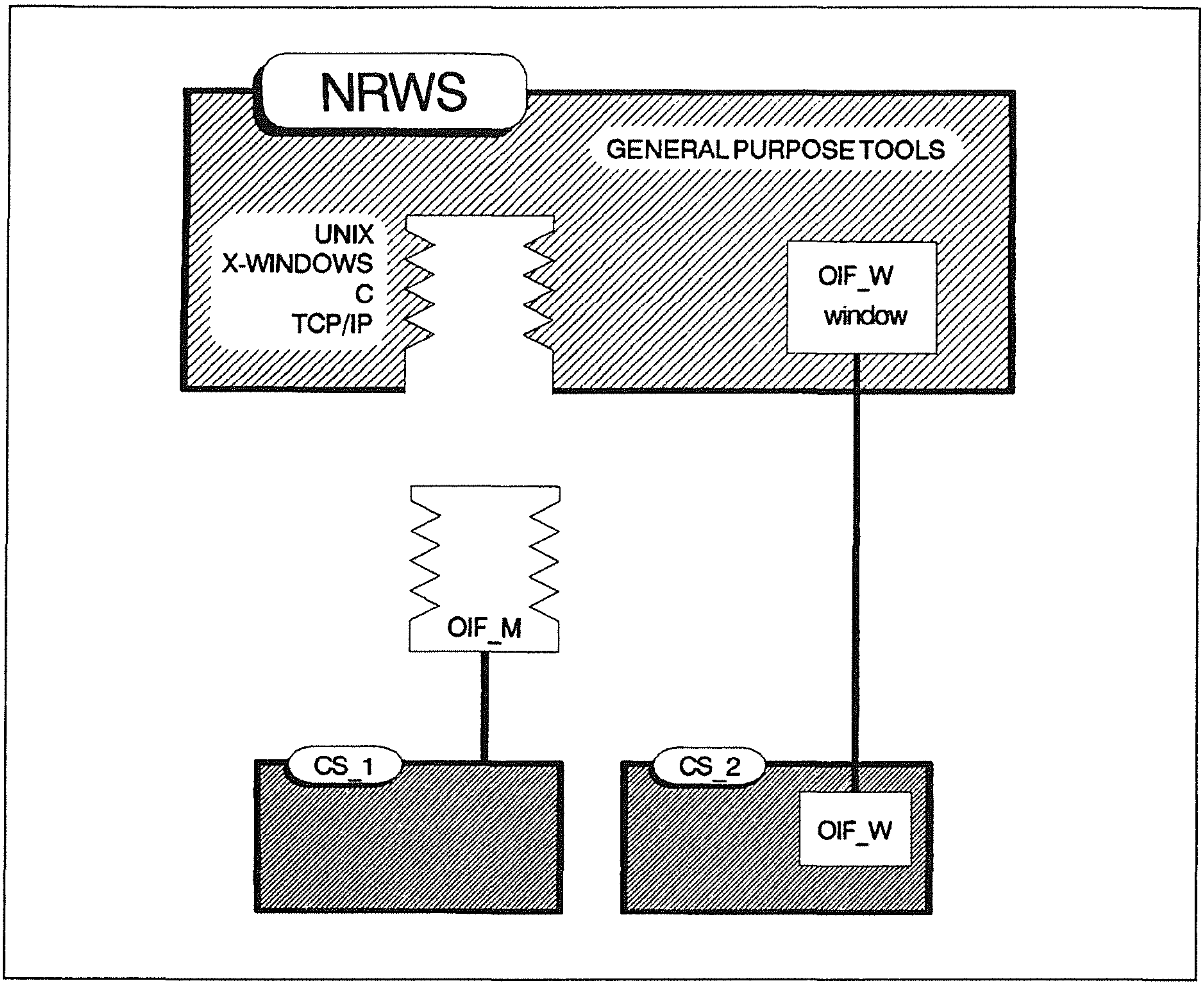

Figure 46. NRWS and RH-area control system operating interface. For operating the RH-area control system has to provide an interface module. Two types are possible are possible for integration into the NRWS: (1) a module (OIF_M) runnable on the NRWS or a general purpose workstation providing the same internal interfaces, or (2) a module (OIF_W) running on the RH-area control system, accessible via an X-server by opening a X-window (OIF_W window). CS_1 may for example be the IVHU area control system.

19.6 Central Utilities Interface

The interface to the central utilities is defined as an X-window interface concerning the operator's access to the utilities. The data format for access to the utilities from a NRWS module has TBD.

From the operational point of view the access to the central utilities is provided as general services (software, facilitating the work with the utilities). Essentially this are access modules to databases or communication links which are state of the art and which only have to be integrated.

Section 5. Conclusions

The NRWS represents a new control system component for telemanipulation (telerobotics) which combines proven control system techniques for telemanipulation and advanced operator support modules. The NRWS is designed highly modular as an open system such that a stepwise perfection is possible. The NRWS is operational with a minimal submodul set that means for example with the minimal MMI (the operating interface) together with the spatial simulation system, a configuration in principle already successfully proven in the JET environment.

The general approach taken in this proposal for the NRWS design is in accordance with similar developments in related fields of telerobotics and man-machine cooperation.

The operator support modules based on procedure simulation and functional simulation should be designed in detail and developed. All the NRWS components then have to be integrated to a prototype which has to be applied to a realistic task.

As a general conclusion the definition and/or selection of standards facilitating the integration of the NRWS itself and the integration of the NRWS into its environment should be done as soon as possible.

Section 6. Recommendations

20.0 Future Work

The implementation of a NRWS as proposed seems to be promising. Therefore a step-wise implementation of a prototype for EDITH is recommended with the goal to investigate its usability in a realistic task. The reference task for these test could be the divertor replacement which will be done with EDITH in a mock-up.

This work is based on significant developments done until now and therefore is a straight forward advancement of the previous work.

1. spatial simulation (KfK in cooperation with JET),
2. integrated viewing (KfK in cooperation with JET),
3. functional simulation and monitoring (power plant industry)
4. selected areas of standardization (KfK, ISO, DIN, TELEMAN).

The work to be done in the future may be partitioned into two groups: (1) general investigations and decisions needed for the whole control system and (2) specific work related to a NRWS prototype. In a third subchapter a time schedule is proposed.

20.1 General Work

The most important work areas related to the whole NET control system in the near future are:

1. Definition of standards needed as boundary conditions for all kind of control system development (NCS and RHCS). Proposals are found in Table 2 on page 126.
2. Specification of central utilities for remote handling and their relation to NCS utilities (e.g. databases, CAD, communication).
3. Specification of services providing access to central utilities.

20.2 NRWS Prototype Related Work

Based on the proposed NRWS design a detailed design of a NRWS prototype for the EDITH test site should be performed followed by a development of a EDITH remote workstation (ERWS) to be attached to the EDITH control system and tested for example in the divertor maintenance task. Installation of a general test site for telerobotics including a control room with a complete prototypic NRWS attached to EDITH is highly recommended. The following work packages are proposed:

1. Research and development in the area of procedural simulation as the base for planning, operator guidance/advice, and high level monitoring (procedure visualization).
2. Research and development in the area of functional simulation as the base for high level monitoring (process/function visualization).
3. Ergonomic research on MMI layout (panel layout) and control room layout.
4. Investigation of applicability and integration of knowledge based techniques and support systems in the context of the NRWS.
5. Integration of the various workstation modules (the advanced techniques/modules with the already proven techniques/modules) to a ERWS as a NRWS prototype. Integration of NRWS modules from different sources should also be done to approve the openness of the architecture.

6. Design and installation of a RH control room for EDITH to provide a general test site for NRWS prototype and NRWS module tests. Special attention should be payed to the possibility of testing and integrating modules from different sources.
7. Demonstration of the usability of the NRWS prototype in a realistic task environment.

The EDITH framework is a best suited environment for implementing and testing step-by-step a prototype of the NRWS. The standard example for operator support function testing could be the divertor exchange.

20.3 Time Schedule

A possible temporal integration of NRWS work into the general NET schedule is shown in Figure 47 on page 113.

	1990	91	92	93	94	95	96	97	98	1999
-NET-										
Pre-design	====									
- requirements										
- specifications										
Prototype developm.	====	====	====	====	====	====				
- components										
- mock-ups										
Design & manufactur.					====	====	====	====	====	====
-EDITH-										
manufacturing	===									
testing		==								
div. hand. tests		=	=							
-NRWS-										
Def. of standards	====									
Spec. central utils	====									
Central utilities		====	====	----						
Def. of databases	====									
Filling of databases				====	====	====				
EDITH-NRWS-prototype	====	====	====	====	----	----				
Spatial sim. (KISMET)	----	----	----	----	----	----				
Procedure simulator	====	====	====	====	----	----				
Functional simulator	====	====	----	----	----	----				
MMI panel	====	====	====	----	----	----				
Integrated viewing	====	----	----	----	----	----				
Logging		====	----	----	----	----				
Guidance		====	====	====	----	----				
Planning/programming		====	====	----	----	----				
Communication/dialog		====	----	----	----	----				
Monitoring			====	----	----	----				
Training				====	----	----				
Configuration										
Commissioning/test.										
Integration & test			==	====	====	====				
Control room		====	==--	----	----	----				
	1990	91	92	93	94	95	96	97	98	1999

===== : development
----- : prototypic applications (EDITH, divertor handling)

Figure 47. Schedule for future work in NRWS development

Section 7. Appendixes

Appendix A. Requirements Definition Document for NRWS

A.1 Introduction

This document defines the requirements for the NET Remote Workstation (NRWS). The requirements are divided into two sections:

1. The general requirements of the NRWS describe the tasks which has to be performed by the operator and the control system, that means the general requirements are the task oriented requirements.
2. The specific requirements are those which are NRWS or tool oriented that means requirements demanding a special type of support for the operator and demanding a special implementation basis.

The philosophy behind the introduction of remote handling workstations into the NET control system is based upon the following facts and ideas:

1. All subsystems for remote handling (e.g. IVHU, BHU) should have the same interface for the operator (as far as possible)
2. General purpose support functions of the RH control system (RHCS) e.g. geometric/kinematic information processing for various purposes, camera control, should be concentrated into a special system, the NRWS, for making them as efficient and convenient as possible.
3. Task-level support functions for the operator such as a simulation, programming aids, or an operator guidance should be implemented on specialized hardware and in a special software environment and be separated from low level control system functions, that means they should be implemented on the NRWS.
4. The NRWS should form an integrating and coordinating unit for the different control subsystems.

Whether the NRWS should be designed as a general purpose workstation or as a special purpose workstation is discussed in Section 3, "NRWS Alternatives, Trade-off, and Recommendations" on page 49.

The NRWS as a subsystem of the RH control system which itself is a subsystem of the NET control system of course has to follow the requirements valid for the NET control system documented in [61] and [62]. The requirements called for in these documents will not be repeated in this context.

A.2 General Requirements

The remote handling equipment at NET (e.g. transporters, manipulators, cameras, lights) will be controlled from the Remote Handling Control Room (RHCR). The working place for the remote handling operators will be one or several NET Remote Handling Workstations (NRWS), which represent the only interface to the remote handling process during normal maintenance operations. The NRWS has to provide access to all software or hardware tools which the operators directly need for performing the maintenance work. During the work a NRWS is attached to the control system of one maintenance area (RH area). An example for such an area control system is the IVHU control system including all its supporting and related subsystems like boom control system, work unit control systems, camera control system, welding control system etc.. All NRWS are expected to be arranged in one central remote handling control room (RHCR).

A prototype of such a remote handling workstation already exists at JET. Experiences with the JET workstation and its environment represent the basis for the NRWS requirements.

The following subchapters describe the environment in which the NRWS has to operate and for which the NRWS has to provide support. But the NRWS should be designed to be flexible enough to include additional tasks which have not yet been defined.

A.2.1 Maintenance Tasks and Equipment

In this chapter *preliminary* lists of

1. relevant maintenance tasks and
2. special elementary tasks which have to be performed via the NRWS,
3. equipment which has to be controlled via the NRWS,
4. maintenance sites in which the controlled equipment is working, and
5. subtasks which the operator has to do at the NRWS in performing the maintenance

are given.

A.2.1.1 Maintenance Equipment

For the performance of the various tasks a group of basic transporters and manipulators will be used. For all these systems special tools or end-effectors will be available which are not known in detail until now. Figure 48 on page 120 gives a preliminary scheme for the maintenance sites and the basic maintenance equipment which also is listed below.

1. In-vessel Handling Unit (IVHU)
2. In-Vessel Vehicle (IVVH)
3. Master-Slave Servo Manipulator (MSSM)
4. Bridge Mounted Transporter (BMT)
5. Bridge Mounted Manipulator (BMM)
6. Lower Plug Handling Unit (LPHU)
7. Main Bridge Crane (BCR)
8. Blanket Handling Device (BHD)
9. Contained Transfer Unit Manipulator (CTM)
10. Lower Plug Manipulator (LPM)
11. Reactor Hall Manipulator (RHM)
12. Lower Hall Manipulator (LHM)
13. TV cameras at various positions on different carriers (special arms, pan/tilt heads, fixed/transportable)
14. Various working units like e.g. WU for antenna handling
15. Various special tools like e.g. welding machine

A.2.1.2 Maintenance Tasks

The following tasks have to be performed via the NRWS:

1. In-Vessel Maintenance Tasks
   - Inspection of Plasma Facing Components and Vacuum Vessel
   - Protection Tile Repair and Replacement
   - Divertor Plate Replacement (DN Divertor Config.)
   - Replacement of Plasma Stabilization Coils
   - Replacement of Radio-frequency Antennae
   - Removal of Debris
   - Blanket sector replacement
2. Ex-Vessel Maintenance Tasks
   - Toroidal field coil (TFC) removal
   - Horizontal access port removal
   - Active coil removal
   - Upper P3 coil removal
   - Lower P3 coil removal
   - P1 coil removal

A.2.1.3 Maintenance Sites

The following list of maintenance sites shows in conjunction with Figure 48 on page 120 under which geometrical conditions the tasks have to be done. The NRWS has to provide support to cope with these complex geometric situations. These maintenance sites are:

1. Intercoil Structure
2. Vacuum Vessel Support
3. Toroidal Field Coil Supports
4. Cryostat Upper Sector Seal
5. Upper Shield Plug Seal
6. Lower Shield Plug Seal
7. Upper Segment Vacuum Seal
8. Vacuum Vessel Assembly Bolts
9. Horizontal Access Port Welded Seal
10. Control Coil Feed Throughs
11. Vacuum Vessel Cooling Supplies
12. Poloidal Field Coil Power Supplies
13. Toroidal Field Coil Power Supplies
14. Upper Chamber Blanket-Supplies
15. Upper Access Port Bellows
16. Liquid Helium Expansion Bellows
17. Miscellaneous Connectors

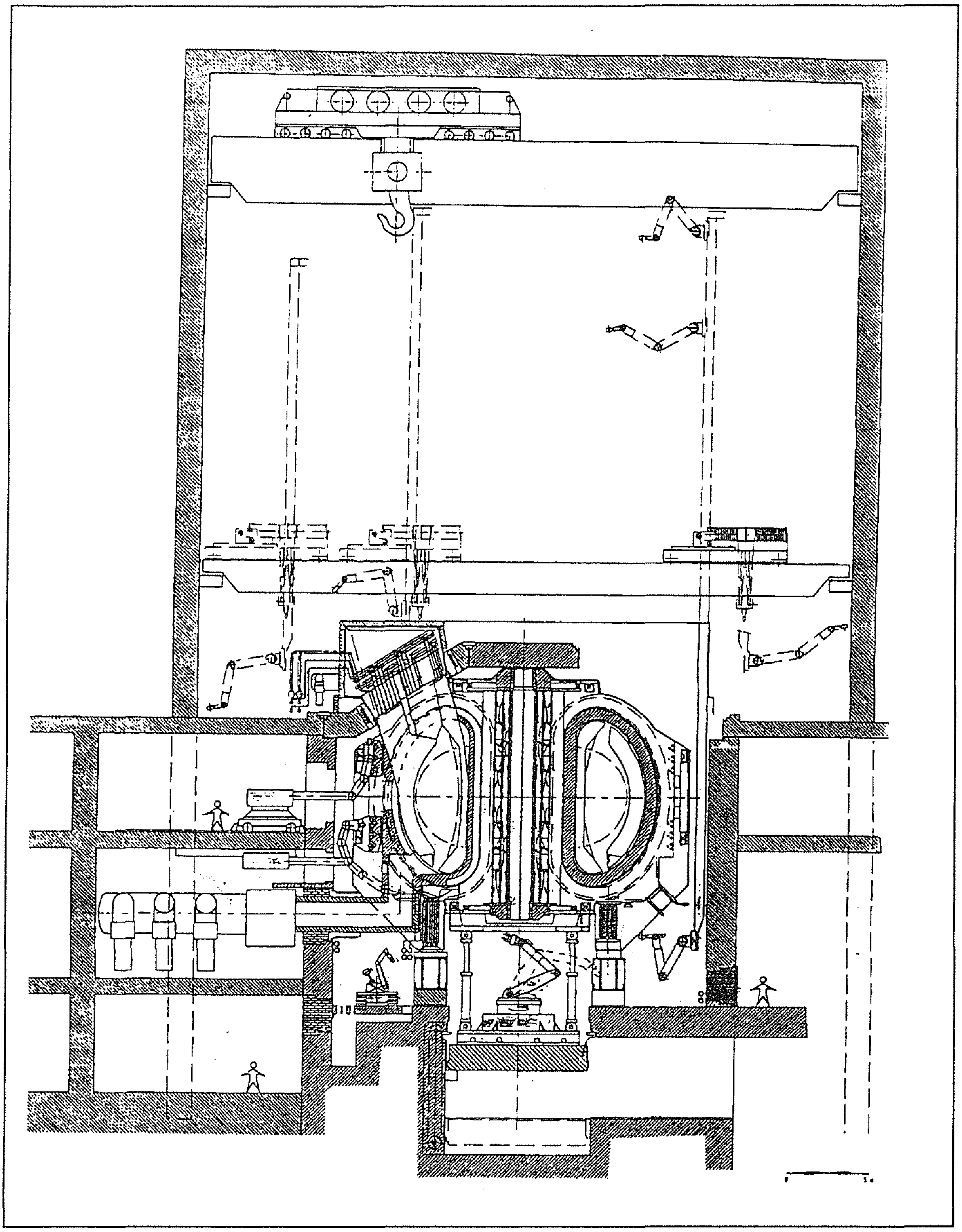

Figure 48. Maintenance sites & equipment

A.2.1.4 Elementary Tasks

Analysing the tasks and breaking them down into small subtasks yields the following group of typical elementary functions which have to be performed and supported:

1. transportation
2. positioning
3. bolting and unbolting

4. removal and storing of elements (debris)
5. presentation of the heating elements (heating resistors or induction coils)
6. release of clamping devices if appropriate
7. machining of welded lip seals
8. elimination of metal chips and cleaning
9. welding of lips
10. inspection of welds
11. installation of tools for handling and extraction
12. coupling/uncoupling of junctions
    - electrical
    - utilities
13. flange engagement and disengagement
14. assembly/disassembly and extraction of piping portions
15. installation and removal of handling tools
16. clamping
17. removal of components

A.2.1.5 Positioning Subtasks

A very important elementary function which deals with geometry is the positioning of tools in different situations. Especially this work governed by geometric restrictions has to be done via and supported by the NRWS.

1. Position screwing/unscrewing device on a bolt or a nut
2. Position a lip seal cutting/rewelding device on a lip seal
3. Position a pipe cutting/rewelding device on a pipe or on rails
4. Position TV cameras in special locations
5. Insert/remove electrical/cryogenic connectors
6. Screw/unscrew a bolt or a nut directly with a screwing/unscrewing end effector
7. Handling of small parts, components and instrumentation with a gripper type end effector
8. Positioning of components or devices hanging on a crane and helping to attach lifting slings

A.2.2 Interdependence of Tasks and Equipment

The NRWS must allow and support collaboration and parallel work of equipment of different RH areas for example cooperation of IVHU and BHD. An provisional overview of collaboration of different manipulators in various operational zones is given in Table 1 on page 122.

Kind of collaboration: TBD

Operation Zone	Involved Manipulators
lower plug	LPM
free corridor	BMT, BMM
upper intercoil structure	RHM, BMM
lower intercoil structure	LHM, BMM
upper plug	BMM
upper chamber	BMM
P4 coil support	BMM, RHM, LHM
in-vessel	IVHU, BMM
blanket area	BHU, BMT, IVHU

Table 1. Operation Zones and Manipulators. Provisional overview showing also the collaboration of manipulators in different zones

A.2.3 Operator Related Subtasks

The following list describes the additional subtasks that an operator may or has to perform during the execution of a maintenance procedure. The NRWS must provide means to support the operator in doing these subtasks.

1. **Preparation of a NRWS for a special task**: After having received the order of performing a special maintenance task (e.g. antenna exchange), the operator has to prepare the NRWS for this special work.
2. **Studying workplans**: This task is usually done using handbooks describing the special task
3. **Training of complete procedures**: The operator has to get familiar with the procedure he has to fulfill
4. **Preparation of site**: The workplace at the workstation and the remote site have to be prepared for the work
5. **Allocation of resources**: The operator has to find out whether the hardware and software tools he needs are available for him and he has to allocate them.
6. **Simulation of subtasks, adaption to actual state of the site**: Before execution the operator should simulate the whole procedure to become familiar with it and to see whether it is in accordance with the actual situation.
7. **Start executive work**: Set the NRWS from off-line to on-line status
8. **Do manual work**: Direct motion control for example with a joystick
9. **Supervise automatic work**: e.g. insertion of the IVHU into the vessel

10. **Intervene**: correction of malfunctions in a preprogrammed procedure (e.g. during preprogrammed transport a part falls down)

11. **Plan unexpected work**: In case of unexpected events the operator has to plan new procedures (work sequences)

12. **Simulate new work sequences**: Newly planned work sequences should be simulated to guarantee their executability

13. **Search in computer lists or libraries for available special purpose tools (in a general sense) to cope with new situation**: Software support tools like special preprogrammed procedures and hardware tools like for example special grippers

14. **Search in computer lists or libraries for comparable preprogrammed procedures**: How did we do a comparable job?

15. **Execution monitoring**: The operator should at least be supported in checking that procedural steps and motion steps have been completed as planned. Automatic checking has to be done as far as possible.

16. **Failure diagnosis**: In case of malfunction the operator should be supported in exploring the actual state of the RH system and in finding failures

17. **Communicate with related RH work areas**: Communication with the responsible operator or exchange of data describing the status of the related areas

18. **Logging**: For documentation, review, and learning. In addition to this automatic logging it has to be possible for the operator to add a operator logging message to the logging sequence. This feature will is needed for the NCS as well, but the detailed requirements may be different.

19. **Helping** In each operational situation a help facility has to be available supporting the operator in all aspects of his work. This facility shall allow for adding personal notes to each help text.

A.3 Specific Requirements

To fulfill the general requirements stated before, the following specific requirements should be used as guidelines for a NRWS design.

A.4 Functional Requirements

The NRWS must provide

1. Command and execution control and

2. Decision aids.

In detail the NRWS should provide the following functions and aids:

1. **Man-machine interface management**(MMIM): The NRWS has to provide the only man-machine interface to the control system and to the controlled RH process. This means provision of (1) status information of all controlled equipment using two- and three-dimensional graphics and standard data presentation techniques and (2) a flexible command input interface including joystick for direct motion control and standard configurable command input aids (softkeys, menus etc.). The interface has to be built such that the work with the master system of a master-slave manipulator can be integrated into the control process. Through the NRWS the operator has to have access to all functions of the RH area control system in a feasible way. This subsystem of the NRWS provides the functions needed to fulfill

the requirements listed in detail under A.4.3, "Man-Machine Interface" on page 127.

2. **Integrated viewing & ligthing**: Viewing by TV cameras and artificial viewing by sensor controlled computer graphics should be integrated into one operator tool. Sensor controlled graphics means to update continuously in real-time geometric parameters of the computer model measured by sensors (e.g. joint angle sensors, bending sensors, assembly mode sensors). The computer graphics should be used for camera control.

3. **Spatial simulator**: The basic module of the NRWS which simulates the remote handling equipment and the maintenance sites geometrically is a a so-called spatial simulator. This basic subsystem is used for planning, training, integrated viewing (execution monitoring).

4. **Functional simulator**: The basic module of the NRWS which simulates the various remote handling procedures (using a special graph model and graphical representation) is the so-called functional simulator. This basic subsystem is used for planning, execution monitoring, training.

5. **Planning support**: The operator must have means available for planning new unforeseen RH procedures and motion paths

6. **Advisory support**: The preplanned RH procedures have to be presented to the operator to guide him (electronic handbook)

7. **Execution monitoring**: The execution of preplanned procedures or motion paths by the operator has to be controlled. At least there should be support functions to make this supervision easier for an operator.

8. **Failure detection**: A module which assists the operator in detecting failures (failure diagnosis)

9. **Collision control**: As a special case of execution monitoring as well as in simulation phase a collision detection/warning subsystem based on a geometric model and sensor signals is needed.

10. **Logging**: All actions of the operator and reactions of the controlled system have to be stored to be available later on for review and analysis.

11. **Work coordination support**: The NRWS must provide the operator with information about the status of related tasks in other RH areas.

12. **Training**: The off-line NRWS (possibly together with the off-line control system) has to provide a training possibility

A.4.1 Implementation Related Requirements

1. **Programmability**: Software solutions should be used as far as possible for input and output functions (e.g. instead of function keys use softkeys, instead of wireing use software communication channels, instead of different displays or instruments use software windows on larger computer displays). Allocation of selectable functions to a standard set of hardware input devices should be possible.

2. **Configurability**: The workstation has to be adaptable to control the work with different RH equipment. This reconfiguration should be easy done by software (configuration files).

3. **Modularity**: Modular architecture for easy maintenance and possibility of upgrading to include additional features. The architecture should be especially designed for implementation in subsequent stages such that advanced features of the NRWS can be added as needed.

4. **Extendability**: Extendable to new or enhanced RH area control systems or enhanced operator support systems and man-machine interface devices

5. **Implementation support**: Implementation has to be based on standard software and using standard software development and management tools (Table 2 on page 126). To allow for a stepwise implementation three implementation stages are tentatively defined (Table 3 on page 127).

6. **Standardization**: Standard internal interfaces (e.g.communication channels, progamming languages) to be adaptable to standard hardware and software products on the market

7. **Function distribution**: If not all NRWS subsystems are implemented on one computer, standard network access methods have to be provided enabling the operator to access all NRWS subsystems from one terminal if needed. (Table 2 on page 126)

8. **Overall response time**: An overall response time (from NRWS via control system to hardware, e.g. from joystick movement to transporter movement, or from e.g. joint angle sensor to NRWS) of TBD ms (e.g. 50 ms[5]) has to be guaranteed.

---

[5] This number is in accordance with requirements of the EC TELEMAN project as a minimum delay time for critical control actions.

Topic	Recommendation	
	short term	long term
Hardware	TBD (IRIS, SUN)	TBD
operating system	TBD (UNIX)	TBD
user interface management system	TBD	TBD
programming language	TBD (C, C+ +)	TBD
CASE-tool (Computer Aided Software Engineering)	TBD (X-TOOLS)	TBD
program management (see: CASE)	TBD (UNIX-make, UNIX-sccs)	TBD
database	TBD (ORACLE)	TBD
communication network	TBD (ETHERNET, FDDI)	TBD
communication protocol	TBD (TCP/IP)	TBD
CAD data format	TBD (combination of IGES, VDAFS,CAD*I)	STEP
motion data format	TBD (IRDATA + add-ons)	TBD (ICR)
control system communication	TBD (MMS like)	ISO/DP 9506: MAP/MMS
window system	TBD (X-WINDOW)	TBD
user environment	TBD (OSF/MOTIF)	TBD
TV	TBD (PAL)	TBD (HDTV)

Table 2. Tentative recommendations for implementation utilities. This hardware, software and standards should be used for implementation of the NRWS. Explanations to these standards are given in "Definition of terms and background informations" on page 141.

Implementation stages	Recommendation	
	short term	long term
1	MMIM spatial simulator integrated viewing collision control logging training (spatial) motion planning/programming support motion monitoring configuration support	TBD
2	procedure simulator advisory support/guidance training support (procedural)	TBD
3	spatial planning support function simulator procedural planning support execution monitoring failure detection	TBD

Table 3. Tentative recommendations for implementation stages. The implementation stages allow for a stepwise implementation of the NRWS

A.4.2 Interface Requirements

The NRWS is working in an environment which demands different interfaces shown schematically in Figure 49 on page 128. The special requirements are subject of the following subchapters.

A.4.3 Man-Machine Interface

The operator interface shall

1. be designed to maximize the operator's control and perception of location, orientation, and movement of the transporter or manipulator with payload, particularly during critical operations or for those requiring extreme dexterity;

2. be designed to maximize the operator's control and perception of the performance of the planned remote handling procedures;

3. provide control features that eliminate the tedium or repetitiveness of frequently performed or routine manoeuvres, trajectories, or operations, and allow these to be executed efficiently and rapidly without jeopardizing collision or safety considerations;

4. be amendable to the addition or adaptation of control features such that the technology changes occurring during the life of NET might be exploited to improve the usefulness and ease of the system;

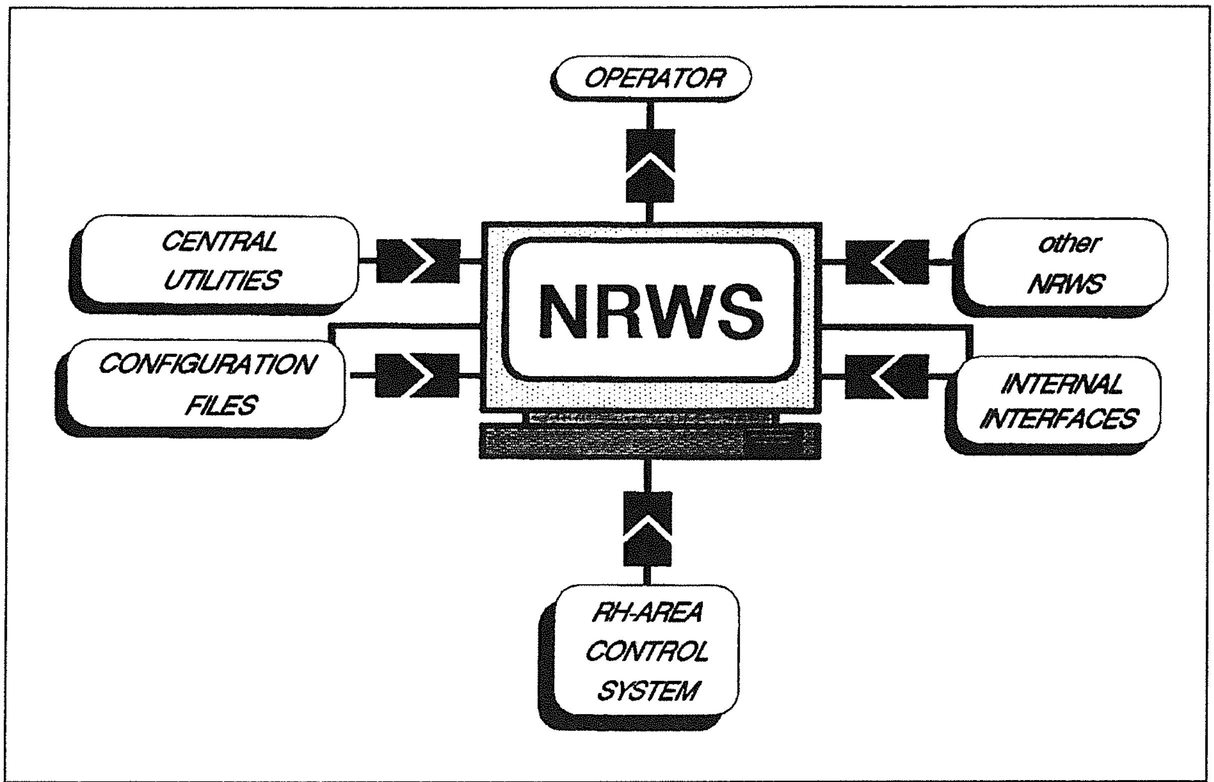

Figure 49. Interfaces of NRWS

5. provide a possibility to change the information arrangement and the command input arrangement (interface layout) easily to be able to adapt it to changed work situations, work phases, or to new operator wishes;

6. provide help functions for all operator commands and information displays,

7. provide operator advice to guide the operator through the planned procedures.

To facilitate the operators work in **state perception** and problem solving as far as possible the system should show views that contain spatial, procedural, and functional information about the tasks being performed and the equipment used. That means the system should provide

1. displays that mimic or simulate commanded motion;

2. active graphic displays that provide plan, elevation, and perspective views of the controlled equipment, payload and environment;

3. TV displays showing the work scene;

4. displays that show in a symbolic form the performance of the procedures (the status of the ongoing work);

5. displays that show the state of the control system itself, including that of the workstation;

6. displays showing values, group of values, or graphical value representations (bar graphs, trend curves etc) describing functions of the equipment.

Concerning the **flexible interface layout** the following specific requirements are important:

1. It must be possible to separate different groups of information on the displays physically and to reallocate them on freely selected screens;

2. It must be possible to attach selectable commands or group of commands to appropriate input devices freely (function keys, switches, joysticks, speech input, speech output etc.) and to define macros;

3. The interface must be designed for later integration of new input and output devices;

4. It must be possible to save and restore interface layouts (to enable arrangement of information or usage of input devices in dependence of phases of work and operator wishes);

5. The set of input and output devices should be minimized, input and output devices should be exchangeable (e.g.all screens should be usable for a special display tasks, input normally done with a mouse should be possible as well with a joystick).

6. It should be possible to eliminate or to iconize information from the screen which is temporarily not needed.

A.4.3.1 Internal Interfaces

To be able to add for example special modules representing the operating interface for a special tool (e.g. welding machine) the NRWS has to have clearly defined internal interfaces to incorporate theses modules and to run them. Details have to be defined, a basis is given in Table 2 on page 126 (UNIX, C, X-WINDOW, MOTIF).

A.4.3.2 Configuration Interface

The NRWS should be configurable by reading data from a special configuration file which has to be easily editable. Format and data of this configuration file (3): TBD.

A.4.3.3 Interface to Central Utilities

The NRWS has to have an interface to central utilities (4) which is described by:

1. Communication network: see Table 2 on page 126
2. Communication protocol: see Table 2 on page 126
3. Window system: see Table 2 on page 126
4. Data in/out: TBD

These central utilities are:

1. CAD-system for model management
2. RH-procedure database
3. RH-resource management
4. General purpose database
5. TBD

A.4.3.4 Interface to RH-Area Control System

The NRWS has an interface (5) to the subordinated area control system (e.g. the IVHU control system including WU control systems, camera control systems, and control systems of special tools like welding machines) which is described by

1. Communication network: see Table 2 on page 126
2. Communication protocol: see Table 2 on page 126
3. Window system: see Table 2 on page 126
4. Data in/out: TBD (in: status information, out: commands) The requirements for an RH-area control system including a detailed functionality is given in the report KfK-Primärbericht 17.01.01P17A. There the functionality is described which is needed to run a control system from a NRWS. An overview over the functionality of a special implementation is also given by Appendix C, "TARM Control System Command List" on page 137. A control system communication standards recommended for this context is the MAP/DIS standard.

A.4.3.5 Interface to Related NRWSs

The NRWS has an interface (6) to other NRWSs controlling related work which is described by:

1. Communication network: see Table 2 on page 126
2. Communication protocol: see Table 2 on page 126
3. Window system: see Table 2 on page 126
4. Data in/out: TBD (status information about the work going on)

A.4.4 Ergonomic Requirements

Ergonomic requirements should be according to an accepted standard (TBD). The control room and the workstation should be designed to maximize operator comfort and to eliminate physical or mental fatigue, distractions, etc.

A.4.5 Reliability Requirements

TBD.

In general: in accordance with NCS requirements.

Redundancy of the NRWS is given due to the fact that the NRWS is proposed to be build as a general purpose NRWS and therefore the available NRWS are interchangeable.

A.4.6 Safety Requirements

The NRWS safety requirements should be in accordances with the related NCS requirements.

1. The back-up control panel has to be completely separated from the NRWS
2. In case of NRWS malfunction the lower level of the control system (the RH-area control system) has to go into a safe state triggered by a message from the NRWS. The NRWS than has to be detachable and an other NRWS has to be configurable

and attachable to the actual RH area control. Prosecution of the interrupted work must be possible. If no other NRWS is available the operation of the RH equipment must be possible using the test interface (handbox) of the RH-area control system.

3. The NRWS has to have a self-test function which signals the result to the lower control system level and to the control room supervisor.

4. The correct execution of planned procedures has to be checked (A.4, "Functional Requirements" on page 123: Execution monitoring) automatically as far as possible and the checking by the operator has to be supported by problem suited aids (e.g. subtask completion messages, problem suited procedure execution states presentation etc.).

5. Exceptional (faulty) equipment actions like sudden movements must be detected, stopped, and signaled to the next higher control system level.

A.4.7 Maintenance Requirements

In general: in accordance with NCS requirements.

Software and hardware maintainability must be in accordance to standard techniques (TBD) in computer and software industry.

A.4.8 Environmental Requirements

In general: in accordance with NCS requirements.

A.4.9 Integration with the NET Control System and NET Operations

The integration of the RH control system into the NET control system has to be done in detail concerning

- equipment,
- procedures,
- communications,
- management,
- maintenance.

This means to use NCS wide management techniques, standards, and tools.

More details have TBD.

A.4.10 Seismic Requirements

TBD

In general: in accordance with NCS requirements.

A.4.11 Other Requirements (TBD)

TBD

A.5 *Relation to General IVHU Requirements*

Table 4 on page 132 shows the relation between general remote handling requirements and derived requirements for the NRWS.

General RH requirements	NRWS requirements
minimize time for operation	- enhanced viewing (synthetic viewing) - automation of transport - computer support for manual operation
minimize time losses due to operator errors	- computer guidance for operator - simulation for planning, programming, training
minimize time for introducing enhancements or special solutions to unexpected events (extendability, integration)	- modular architecture - software implementation - standard development & maintenance tools - thoroughly defined internal interfaces (hardware & software)
safe operation	- motion monitoring - procedure execution monitoring - simulation - hierarchical system structure - reliable behaviour of position controller - software stops based on software models

Table 4. Workstation requirements and related RH requirements

To JET state of the art

[1] Galbiatti, L.: personal communication

[2] Raimondi, T.: personal communication

[3] Rolfe, A.: personal communication

[4] Galetsas, A.: personal communication

[5] Galetsas, A.: unpubished report, 1989

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Appendix C. TARM Control System Command List

```
=========================================================================
SESSION CONTROL
-------------------------------------------------------------------------
LOGIN        establish a session and assign privileges
LOGOUT       terminate a sessin
-------------------------------------------------------------------------


=========================================================================
DISPLAY COMMANDS PRODUCING SINGLE MESSAGES
-------------------------------------------------------------------------
SHOW_OPERATOR_PARMS display operator parameters
SHOW_SYSTEM_PARMS   display system parameters
SHOW_ERROR_LOG      display content of fault file
SHOW_DIRECTORY      display list of all repeat sequence files
SHOW_OPERATOR
SHOW_REPEAT_SEQU_D  display description of repeat sequence
SHOW_POINT          display point list or single point coordinates
SHOW_LOADS          display measurements of B2 bending
SHOW_LIGHTS         display lights status
-------------------------------------------------------------------------


=========================================================================
DISPLAY COMMANDS PRODUCING PERIODICAL MESSAGES
-------------------------------------------------------------------------
MONITOR_MOTION_LOAD_STATE
MONITOR_ALIGNMENT_DEVIATION
MONITOR_JOYSTICK_CONTROLLED_AXES
MONITOR_OFF
-------------------------------------------------------------------------


=========================================================================
SET SYSTEM PARAMETERS
-------------------------------------------------------------------------
SET_SYSPARMS_INTEGRITY_CHECK          set values for specified group
SET_SYSPARMS_MEASUREMENT              set values for specified group
SET_SYSPARMS_OPERATIONAL_MONITORING   set values for specified group
SET_SYSPARMS_PATH_PLANNING            set values for specified group
SET_SYSPARMS_PID                      set values for specified group
SET_SYSPARMS_SERVO_LOOP               set values for specified group
SET_SYSPARMS_ERROR_HANDLING           set values for specified group
-------------------------------------------------------------------------
```

```
========================================================================
SET OPERATOR SETTABLE PARAMETERS
------------------------------------------------------------------------
SET_VELOCITY             set max. axis velocity
SET_ACCELERATION         set max. axis or PoR acceleration
SET_DECELLARATION        set max. axis or PoR deceleration
SET_OVERRIDE             set override factors
SET_POR                  define PoR vector relative to A4 joint
SET_FLYPOINT_TOL         set tolerance area for flypoint
SET_POSITION_TOL         set accuracy requ. for maincrane moves
ALIGNMENT_CHECK
MODE_MOTION/SIMULATION   set operating mode
SET_SIM_CONFIG           def. operation configuration for simulation
SET_SIM_POS              def. simulated position of joints
------------------------------------------------------------------------
```

```
========================================================================
PARAMETER DATABASE OPERATIONS
------------------------------------------------------------------------
SAVE_SYSTEM_PARMS        store system parms in database
SAVE_OPERATOR_PARMS      store operator parms in database
RECALL_SYSTEM_PARMS      load system parms from database
RECALL_OPERATOR_PARMS    load operator parms from database
------------------------------------------------------------------------
```

```
========================================================================
SYSTEM INTEGRITY CHECK
------------------------------------------------------------------------
CHECK_ALL_JOINTS         initiate hardware tests on LLCS
CHECK_JOINT              initiate hardware tests on LLCS
------------------------------------------------------------------------
```

```
========================================================================
MOTION CONTROL MODE CHANGING COMMANDS
------------------------------------------------------------------------
ASSIGN                select joints or PoR for joystick control
JOYSTICK              enter/leave velocity control mode
FREEZE_PoR            select joints to be fixed in PoR move mode
PoR_CONTROL           select world/tool coordinate system for PoR moves
SET_ELBOW             select solution of singularities
DOCKING               enter docking mode (no teaching, repeating,ed.)
JOINT                 releases joint for hand movement
------------------------------------------------------------------------
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MOTION CONTROL COMMANDS	
MOVE_JOINT	position control of axis (axis space)
MOVE_TARM	position control with symbolic points
MOVE_PoR	resolved motion control
LIGHTS	lights on/off
STOP	emergency stop, brakes immidiately engaged
HALT	gentle stop, max. allowed acceleration
CONTINUE	motion enabling after stop/halt

TEACH & REPEAT FUNCTIONS	
TEACH	enter teach mode
MODIFY	edit existing teach file
EXECUTE_SKIP_n	execute teach file, skipping n commands
SKIP_n	skip commands in repeat sequence
INSERT	enter insert submode of modify mode
END_INSERT	terminate insert submode
DELETE	delete the next command in currently edited prgrm
STEP	execute the next n commands in the sequence or execute the next MOVE command and allow modification of all referenced points
HERE	define a named point and return to previous submode
UNDO	return to the state before the last recorded cmd
PAUSE_text	define restpoint and display text for operator
RESUME	resume execution
EXIT	exit teach/edit mode, preserving output file
ABORT	terminate teach/edit and delete output file or terminate repeat/simulation immediately

REPEAT SEQUENCE EXCHANGE	
TRANSMIT	transmit repeat sequence file to workstation
RECEIVE	receive and store repeat file on microVAX

A

Action net. An action net is an abstract graph representing a RH procedure. The nodes of this graph are actions (subtasks, elementary task steps) and facts. Actions may be performed when relevant facts are given. If an action is finished, new facts are produced. Action nets are closely related to Petri nets.

C

CASE-tool. Software development and maintenance should be based on so-called "Computer Aided Software Engineering" tools. These tools include structured development of software and software version management.

Central utilities. Central utilities provide resources of system wide importance like databases, communication means etc. These system wide resources are made available to the user by special services.

Communication protocol. Defines the communication between computers. The actually mostly used standard in the UNIX workstations environment is TCP/IP. In the future ISO/OSI standards (e.g. MAP: manufacturing automation protocol) should be selected.

Communication network. As physical and data link layers of communication in an non-real-time environment Ethernet (IEEE 802.3) is mostly used; in the real-time environment a Token bus system (IEEE 802.4).

Control system data exchange. For the communication between manufacturing system components (control systems, computers, robot systems, man-machine interface, etc.) the MMS (manufacturing message standard) is being in ISO.

CAD data format. This is the format describing model data. Formats used in practice are IGES (no solids), VDAFS (only surfaces), CAD*I. An upcoming standard from ISO is STEP, describing general product data.

Control system data exchange. For the communication between manufacturing system components (control systems, computers, robot systems, man-machine interface, etc.) the MMS (manufacturing message standard) was defined in ISO. The basic services of MMS are:

- Virtual Manufacturing Device Support, Environment and general management,
- Domain (program and data) management services,
- Program invocation management services,
- Variable access services,
- Event management services,
- Semaphore management services,
- Operator communication services,
- Journal management services.

Control system area. An area is a functional grouping of equipment, such that it can be operated and commissioned independently, and that minimizes communication requirements with other subsystems.

D

Database. A widely used relational database which may be used for implementing different application databases for remote handling is ORACLE.

E

EDITH. Short term for "Experimental Device for In-Torus Handling". EDITH as a whole will include the transporter, work units, manipulators, and the required mock-ups for typical tasks. EDITH is planned as a test field for the RH control system including the NRWS. The NRWS prototype planned for EDITH is called ERWS.

Expert system. A system operating on a knowledge base deriving new explicit facts out of implicit knowledge. Standard applications of expert systems are diagnosis, planning, surveillance (monitoring), decision making, advice. Possible abilities of the expert systems are: recognition, searching, inferencing, learning.

Functional model. A functional model of the equipment represents the equipment by sets of "process" variables and their interdependencies.

Frame. Local coordinate systems displayed with the geometry if needed which serve for easy manipulation. For example a gripping position of a divertor plate may be represented by a frame. In this case the command GRIP DIVERTOR leads the work unit to the right position.

G

Graph. Symbolic diagram expressing a system of connections of nodes and arcs (net).

Guidance. (1) Guidance of the operator (2) Highest level of the control system, also named tasking level

H

Hardware. As hardware base for the development of the NRWS general purpose engineering workstations (e.g. SUN) and high performance graphics workstations (e.g. Silicon Graphics IRIS) should be used. Those workstations are characterized by a high resolution display, at least 8 MB memory, high performance CPU, at least 100 MB disk space, Ethernet controller, and special graphics engines

Hierarchical control system. A control system separated into different control levels for an effective and safe coordination of various control system subtasks. Outputs of higher levels are being used as input commands for lower levels, and lower levels furnishing status reports for higher levels. Each level in the hierarchy accepts tasks from the level above it and splits those tasks into subtasks that are parceled out to the levels below it. Such systems tend to be fast and efficient, because they can be designed so that decisions are made no higher in the architecture than necessary. The RH control system differentiates between three levels: Guidance/task level, motion level, equipment/drive level. Comparable levels of the NCS architecture are: Central level, area level, local level. The naming in the latter case is more related to aggregation, the naming for the RH control is oriented to task decomposition. A widely accepted control hierarchy for telerobotics is the NASA NASREM structure (also discussed in ESA and EC TELEMAN projects).

I

Integrated viewing. A subsystem of the NRWS which integrates standard TV based scene presentation with a an advanced scene presentation by sensor controlled computer graphics. Camera control supported by computer graphics is included.

K

Knowledge based system. The knowledge of knowledge based system is characterized by a high complexity of its structure, much more complex than the structure of data in standard databases. Knowledge is normally represented by rules and/or by object nets. Standard algorithms in such systems are search algorithms and inference algorithms. Those KB systems can apply that knowledge to solve problems in a way an expert does. Such KB systems will make the computer less a tool than a partner or assistent with more flexibility than previous systems.

M

Monitoring. Presenting (visualizing) the state of a system on various levels of abstraction (e.g.spatial, functional, procedural) for an operator and in an advanced state automatic surveillance of a system under various aspects.

Motion data format. Such a data format describes robot tasks in form of robot programs. A DIN-standard for this kind of data exchange needed between the NRWS and RH-area control system (e.g. the IVHU control system) is IRDATA (Industrial Robot Data). Further standardization activities are underway in ISO: ICR - Intermediate Code for Robotics is the name of the standard being in discussion and which will probably replace IRDATA in the future.

Mimic. Abstract representation of a things with expressive geometry

MMS. MMS is the most important application in MAP. MMS provides in layer 7 of MAP a uniform communication between control system components. These MMS features are accessible via special services described in ISO 9506. MMS uses a client-server interaction model.

See also: "Control system data exchange".

N

NET remote handling workstation (NRWS). Workstation at which the RH operator is sitting to perform RH procedures, to do maintenance work. The NRWS provides the man-machine interface to the control systems and a various high level (task oriented) support tools for the operator. The NRWS represents the "guidance system" of the RH control system.

NET control system (NCS). The overall control system of the NET plant as described in [61]The hierarchy of the NCS is represented by three levels: Central - Area - Local. The RH control system is a subsystem (an area) of the NET control system.

O

Operating interface. Basic software module providing the information and commands needed to control a RH machine. The operating interface may be runnable on different hardware (NRWS, handbox, RH-area controller).

Operating system. A more-or-less general-purpose computer program which controls the execution of the specific "application" programs run on a computer. An operating system provides the critical interface between the computer hardware and the humans that use it, handling things like program scheduling, the "input" and "output" of data, detecting and diagnosing errors in the performance of application programs, and other housekeeping chores. The actual standard OS for workstations is UNIX.

OSI. Open System Interconnection is an ISO standard structuring communication systems by definition of 7 levels. Each level has to fulfill a special subtask of the communication function. These levels are: Physical Layer, Data Link Layer, Network Layer, Transport Layer, Session Layer, Presentation Layer, Application Layer.

P

Panel. The hardware of the man-machine interface: input devices, output devices, the assembly hardware, and the computing hardware and software needed to form a standard interface (server functionality).

Petri net. A Petri net is describing a process by situations and transitions. Transitions propose the validity of certain situations related to them. On the other side transitions produce related post-situations. The progress of a process is represented by a sequence of situations. Especially the concurrency of transitions can be modelled easily. This modelling technique is characterized by a sound mathematical background for analysing processes and its ease of use based on the graphical representation of the nets and the resulting distinctness.

Procedural model. A procedure model represents the maintenance procedures in a formal way using elementary working steps (see: RH procedure)

Programming language. The generally used programming language workstations running the UNIX operating system is C

Program management. Program management tools are normally included in CASE tools.

R

RH control system (RHCS). All control system components controlling remote handling equipment are integrated hierarchically to the RH control system. This is a subsystem of the NET control system and connected to it via a LAN bridge.

RH-area control system. The RH control system is partitioned into so-called RH-areas, control system complexes integrating the control system components needed for controlling a major manipulator (e.g. IVHU, BHU) and its supporting devices. A RH-area has a separate communication channel, the RH-area bus. Manufacturing cells in manufacturing plants are similar units.

RH-area bus. LAN connecting the controllers of a RH-area

RH bus. LAN connecting the NRWSs with a bridge the NCS LAN.

RH procedure. Documentation of the preplanned work to be done in RH. The RH procedures describe the work step-by-step using elementary subtasks and specifying the conditions required for performing those subtasks, including the availability of resources.

S

Spatial model. A spatial model represents the maintenance equipment and the working environment by its geometry and kinematics.

Symbol. Mark or character taken as the conventional sign of source object or process

T

Task/guidance level. The highest level in the control system hierarchy dealing with tasks and subtasks of the maintenance process. The software support tools of the task level are running on the NRWS.

Task net. See: action net

TELEMAN. TELEMAN is a project of the Commision of the European Communities dealing with Remote Handling in Hazardous or Disordered Nuclear Environments. The objective of the program is to develop advanced teleoperators which will reduce present man-dose levels, improve productivity and enable public authorities to deal more effectively with nuclear accidents.

U

User environment. To standardize application presentations (the user interface of a software tool) the OSF/MOTIF standard (Open System Foundation) and the OPEN LOOK standard (AT&T, SUN) were defined. Those packages are running on top of X-windows. For example the MOTIF standard offers:

- a common user interface for all NRWS modules and on all panel displays,
- a single, stable, widely available applications programming interface,
- easy to use interactive behaviour of interfaces,
- a distinctive 3D appearance of the windows.

The MOTIF tools are:

- application program interface,
- user interface toolkit,
- presentation description language,
- window manager,
- style guide.

User Interface Management System (UIMS). To provide a high control system flexibility the subtask of user interfacing (dialog management) is implemented as a special relatively independent subtask (the UIMS) separated from the application or support modules. This separation facilitates the management of the man-machine interaction.

W

Window system. A window system (window manager) is a software package which helps the user (operator) to monitor and control different context (subsystems) by separating them physically onto different parts of one or more display screens. At it simplest, a window manager provides many separate terminals on the same screen, each with its own connection to a time-sharing computer. At its most advanced, a window manager supports many different activities, each of which uses many windows, and each window, in turn, can contain many different kinds of information including texts, graphics, and even video. The window managers also provide a higher level interface to input and output devices, and therefore they support the implementation of more portable user interfaces. This is especially true for the X window manager. Applications implemented on different computers using the X window system may easily be accessed from other computers also running the X window system. In this sense the X window system can integrate several workstations running different operator support systems to the NRWS.

The X-window system consists of a library of procedures supporting generation and management of communicating windows including related input devices.

Window Client-Server Model. Clients are window oriented applications, which do not manage their input and output by themselves but leave it to a server. The server manages the resources of a terminal (the NRWS-panel) and serves the input/output requests of the client.