KfK 4787
September 1990

Specification of EDITH MOTION CONTROL SYSTEM

H. Breitwieser, A. Frank, E. Holler, U. Süss, K. Leinemann
Institut für Datenverarbeitung in der Technik
Institut für Reaktorentwicklung
Projekt Kernfusion

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE

Institut für Datenverarbeitung in der Technik
Institut für Reaktorentwicklung
Projekt Kernfusion

KfK 4787

Specification of EDITH MOTION CONTROL SYSTEM

H. Breitwieser, A. Frank, E. Holler, U. Süss, K. Leinemann

KERNFORSCHUNGSZENTRUM KARLSRUHE GMBH, KARLSRUHE

Kernforschungszentrum Karlsruhe GmbH
Postfach 3640, 7500 Karlsruhe 1

ISSN 0303-4003

ABSTRACT

EDITH is an experimental device for in vessel handling at NET/ITER. The purpose of EDITH is:

- testing of ABS (articulated boom system) components
- testing and validation of remote handling procedures
- testing and validation of ABS end-effectors
- testing of ABS control system features and verification of control system concepts

This document, after describing the environment in which the control system is to operate, specifies architecture and functionality to be implemented by the EDITH motion control system software, thereby taking full reference to the control system specification for TARM ,which was decided to be the base for the implementation.

ZUSAMMENFASSUNG

Spezifikation des EDITH Bewegungssteuerungssystems

EDITH ist eine Experimentiereinrichtung für Handhanbungsaufgaben im Vakuumbehälter des NET/ITER. Ziel von EDITH ist es:

- Komponenten des ABS (articulated boom system) zu testen
- Fernbediente Handhabungsvorgänge zu testen und zu überprüfen
- ABS Endeffektoren zu testen und zu überprüfen
- Eigenschaften des ABS Steuerungssystems zu testen und die Konzepte des Steuerungssystems zu verifizieren.

Nach der Beschreibung der Umgebung, in der das Steuerungssystem arbeiten soll, spezifiziert dieser Bericht die Architektur und die Funktionalität, die im Bewegungssteuerungssystem von EDITH implementiert werden muß. Dabei wird auf die Spezifikationen des TARM Steuerungssystems Bezug genommen, die als Implementierungsbasis festgelegt wurden.

PURPOSE

This document specifies the requirements for the EDITH Motion Control System which is basically to be derived by adaptation of the existing TARM control system, which was built for JET.

In functional respects it shall conform to the requirements for the ABT control system. With respect to implementation it has to fulfill some special demands concerning the needed flexibility for experiments and the continuity of collaboration with JET

CONTENTS

1. Overview: EDITH as an experimental device for in vessel handling

EDITH is designed as an Experimental Device for In-Torus Handling.

Design, manufacture and testing of EDITH have been identified as a prime requirement to demonstrate the feasibility of the ABS (Articulated Boom System) and to optimize its components and subassemblies selection.

Testing with EDITH proceeds along two main directions:

1. Validation of the concepts chosen to solve critical issues for ABS (e. g. sensors, drive units, kinematic model, control system)
2. Validation of operating procedures, including the test of work units in order to provide relevant feedback for the work units engineering design and the machine components design as well as an assessment of the operating procedures themselves.

The in vessel maintenance tasks /1/ like

replacement of divertor plates
replacement of protection tiles
replacement of RF-antennae
inspection of the first wall and the plasma chamber
replacement of plasma stabilisation coils
leak detection and repair
housekeeping

have to be carried out by means of the ABS. In order to qualify the ABS to perform these tasks, different types of so- called work units (WU's) can be combined with the articulated boom transporter (ABT) to form a handling system with adapted capabilities.

Three different work units have been conceived so far: a manipulator unit (MU), an antenna handling unit (AHU) and a divertor module handling device (DHD).

Fig. 1.1 shows the ABS being equipped with the divertor module handling device. Fig. 1.2 to 1.4 show the preliminary drafts of the antenna handling unit, divertor module handling device and manipulator unit respectivelly. They have to be updated according to the actual requirements for NET/ITER.The above figs. are given to provide an idea of the proposed work units. This does not mean, that all kinds will actually be built. Rearrangement of axes might also occur in the actual designs.

A prototypical ABS, called EDITH (Experimental Device for In-Torus Handling) is the necessary step between proof-of principle and the design of the operational equipment for NET. It must generate all information for an optimised design of the operational equipment and be able to demonstrate beyond any doubt that the maintenance and removal of plasma-facing componentes, in particular the divertor plates and protection tiles can be conducted with the anticipated reliability and time under NET typical conditions. Therefore, the demonstrations have to be performed in full scale related to size and weight, and in realistic mock-ups for the most sophisticated maintenance operations (divertor plate and protection tile replacement). EDITH, as shown in Fig. 1.5, is a full scale prototype of the last ABS links, which can be combined with each of the above WU's by means of attachment to the end flange of the transport unit. A trolley, which in fact is just one additional prismatic joint, is not provided with EDITH. Proper positioning of the work units is achieved by a subset of joints of the transporter and the work unit. This subset of joints, which is specific for each work unit, may be thought of as a virtual unit being responsible for initial WU alignment and is thus called "positioning unit".

The technical data of EDITH are shown in table 1.1.

The purpose of EDITH is:

- testing of ABS (articulated boom system) components
- testing of ABS control system features and verification of control system concepts
- testing and validation of ABS end-effectors
- testing and validation of remote handling procedures

Fig. 1.1 Articulated boom System for NET/ITER (ABS)

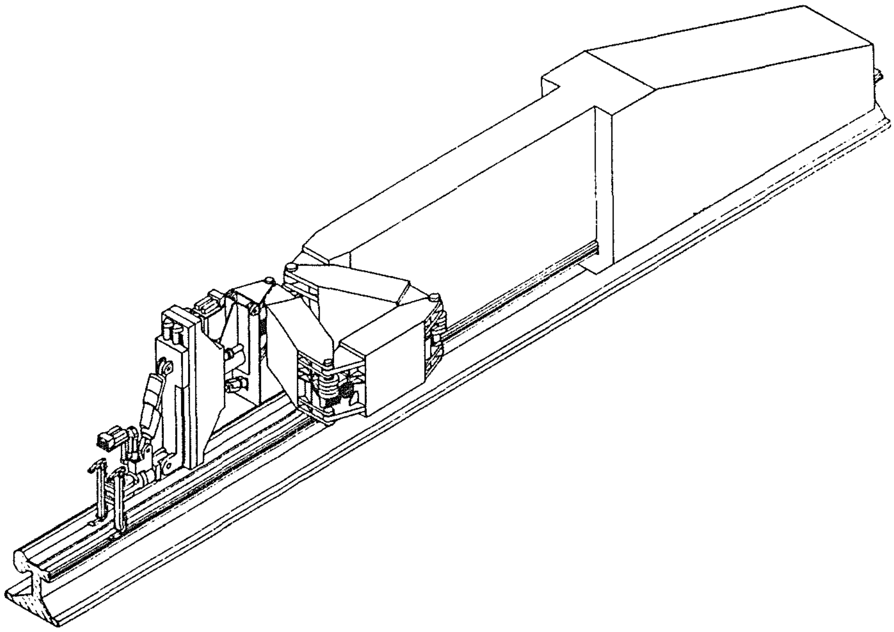


Fig. 1.2 Antenna handling unit (AHU)

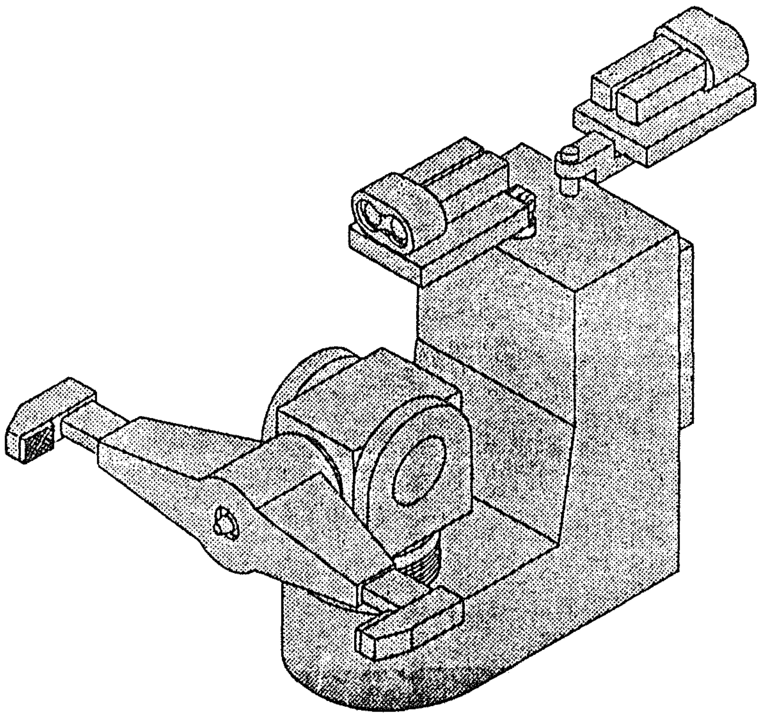


Fig. 1.3 Divertor module handling device (DHD)

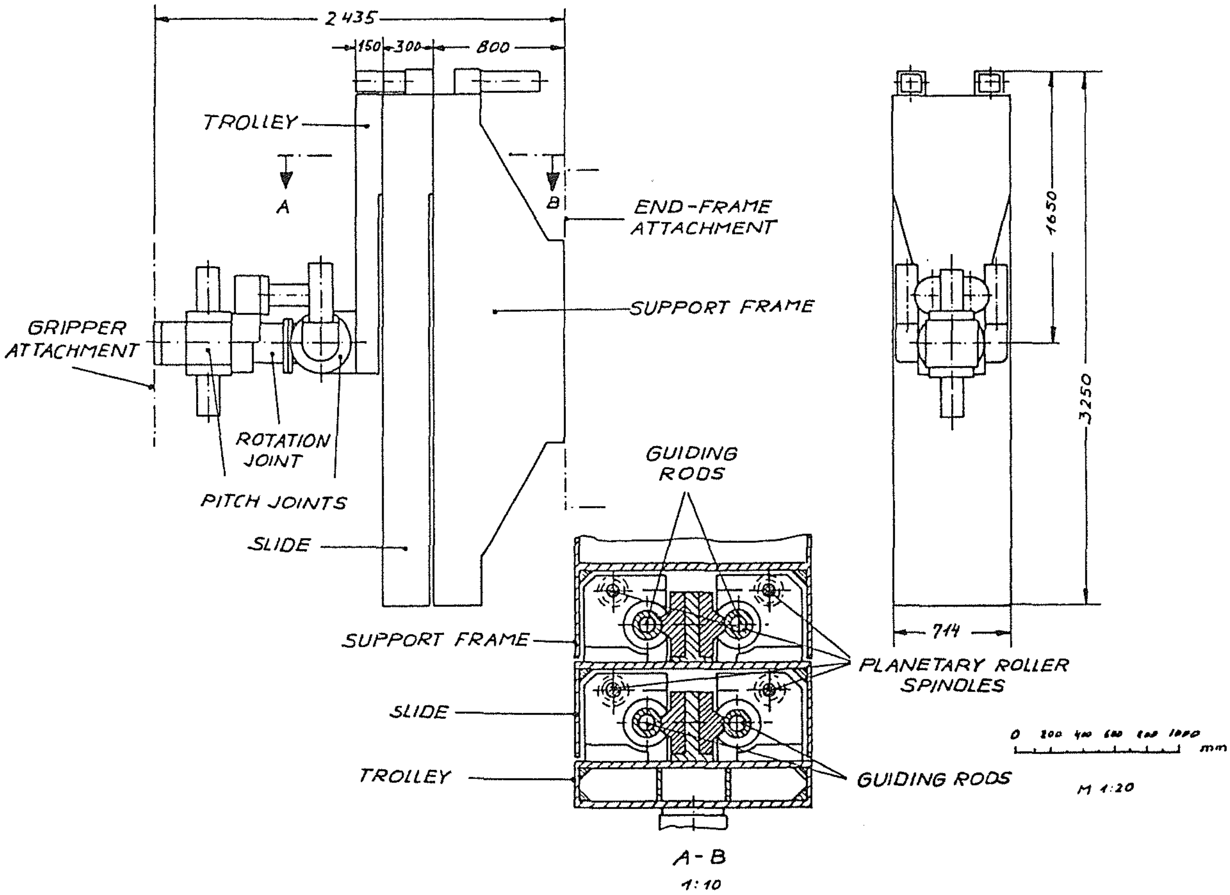


Fig. 1.4 Manipulator unit (MU)

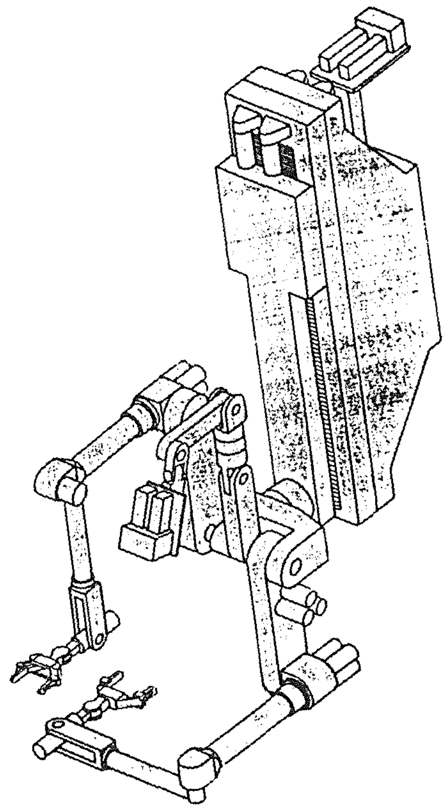
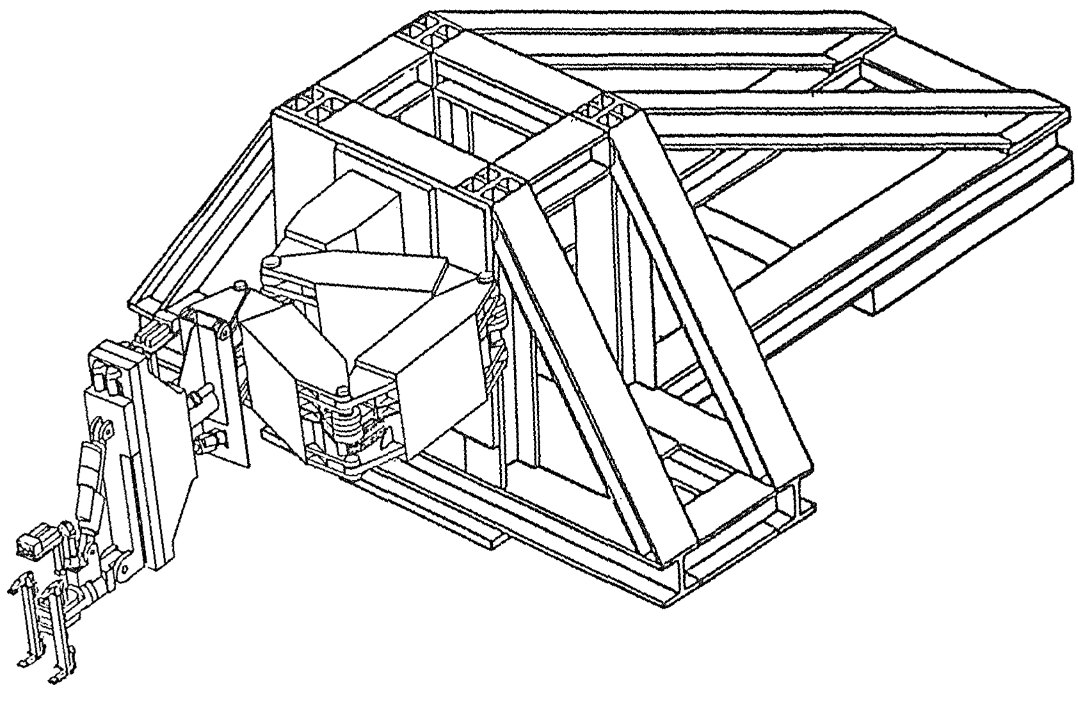


Fig. 1.5 Experimental device for In-Torus Handling (EDITH)



length of articulated boom	8,85 m
total weight of the boom	6,2 tonnes
maximum payload	1000 kg
admissible work unit weight	2900 kg
number of yaw joints	4 range of operation 240°
number of pitch joints (at end frame)	1 range of operation ± 5°
number of roll joints (at end frame)	1 range of operation ± 180°
gear:	
yaw and pitch	FR 75 Cyclo
roll	FR 45 Cyclo
motors	D315 ... L50 Moog Inc.
resolvers	Siemens, Gerwah
servo control	ASB, FSR AC S

Table 1.1 EDITH technical data

2. Requirements for the EDITH control system

Since EDITH is a prototypical test facility, its control system has to fulfill the main requirements of the NET/ITER ABS control system.

These requirements are presented in the following groups:

- General requirements defining a basic framework;
- Functional requirements guaranteeing task execution;
- Operational requirements guaranteeing a good task performance;
- Implementational requirements guaranteeing the integration of the system into the environment.

2.1 General Requirements

The control system has to control the EDITH as the central transport unit, which will at a later stage be controllable from an EDITH Remote Workstation (ERWS). In its first implementational stage the EDITH control system has to be operatable from a transportable interface (handbox) for the purpose of installation and tests. This operating interface (software module) has to be extendable to represent the basic operating interface runnable on the ERWS (c.f. "NET Remote Workstation" [4]). The control system has to be designed for easy extendability. It should be possible to add subsystems controlling EDITH supporting equipment. The various subsystems have to be implementable step by step with the evolving set-up of the complete EDITH system. Subsystems added later on are for example the camera control units.

The general ABS system requirements

- minimization of time for operation,
- minimization of time wasted due to operator errors,
- minimization of time for introducing enhancements or special solutions to unexpected events (extendability, integration),
- safe operation

have to be seen as guidelines for EDITH. With the EDITH control system implementation solutions to obtain these goals shall be investigated. These general guidelines lead to general requirements for the EDITH control system as:

- integration into an hierarchical overall control system,
- computer support for manual operation,
- automation of subtasks (e.g. transport),
- excellent dynamic behaviour,
- modular architecture,
- standard development & maintenance tools,
- thoroughly defined internal interfaces (hardware & software),
- software implementations as far as possible.

The relationship between the general EDITH requirements and the required EDITH control system functionality and architecture are shown in Table 2.1. The subject of this chapter is to detail these general requirements.

The full functionality of the control system must be accessible through the command interface as the only access channel to the control system. This includes parameter setting and status parameter reading.

2.2 Functional Requirements

The required generic functionality of the EDITH control system is in accordance with that for the ABS (Fig. 2.1). The required functions of the EDITH control system form a subset of the functions of the ABS control.

The EDITH is a manipulator (transporter) which is functionally comparable to manipulators in the manufacturing industry. Therefore the required control system functions should be, as far as possible and meaningful, be oriented on standards of the manufacturing field. The most general standard in this context is the ISO-MAP-MMS standard, which includes the following main functions (overview):

- Loading and Saving of programs,
- Starting and Stopping of programs,
- Reading and writing of state variables
- Triggering of functions by events,

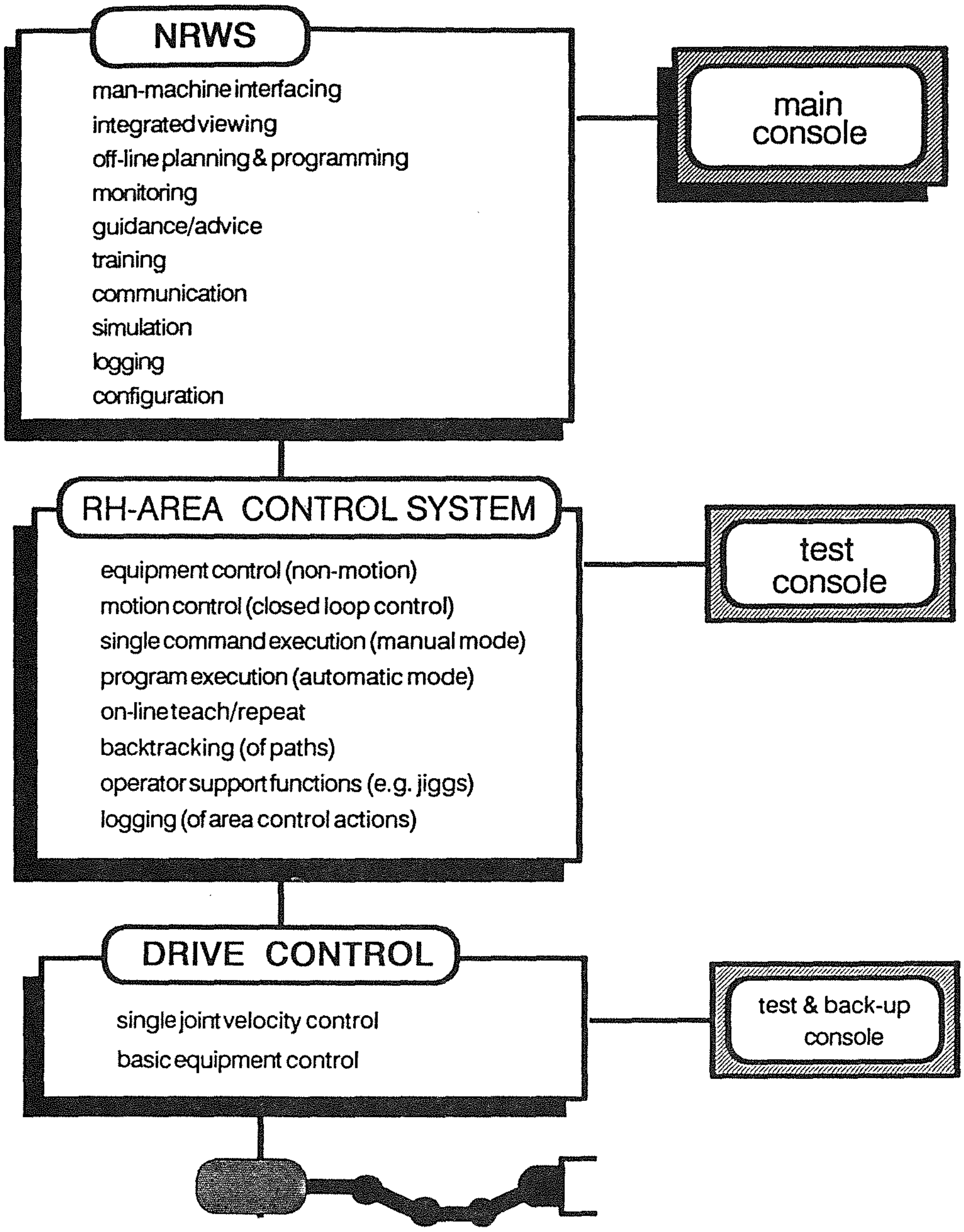


Figure 2.1. **Generic functionality of control system levels**. The NRWS represents the task level support and the man-machine interface, the RH-area control system represents the motion control level functions.

EDITH system requirements	EDITH control system requirements
minimize time for operation	- integrated viewing (*) - excellent dynamic behaviour - automation of transport - computer support for manual operation
safe operation	- simulation in the spatial domain (*) - hierarchical system structure - motion monitoring (*) - reliable behaviour of position controller
minimize time for introducing enhancements or special solutions to unexpected events	- modular architecture - software implementation -standard development & maintenance tools - thoroughly defined internal interfaces (hardware & software)
minimize time losses due to operator errors	- simulation for planning, programming, training in the spatial (*)

Table 2. 1. **Derived EDITH Control System Requirements**. Some of these general requirements (*) have to be fulfilled in cooperation with the ERWS which is not subject of this document.

- Alarm management,
- Storing of state variables.

The basic required functionality of the EDITH control system concerning **motion control** should be in analogy to the functionality specified in [15] as a general interface description for manipulator motion programming. However, because of the special kinematics and application area, the EDITH control system needs in particular the following groups of functions and commands:

Switching between different modes of operation

The control system has to be operatable in two modes:

- manual mode (single command execution, immediate mode),
- automatic mode (program execution).

The automatic mode is entered with the start of a program.

Motion control commands

The control system must provide single joint and resolved motion control in all modes of operation. The special motion description means are described in Appendix A, "Coordinate systems" and Appendix C, "Resolved-motion". In addition to the command which allows to request single joint motion as well as resolved motion command the following commands are required:

- Manual reconfiguration of redundant kinematic
- Detachment of the motion control device, which ends the manual motion control
- Backtracking a previously gone path to a certain extension

Kinematic commands

For motion control in cartesian coordinates as described in Appendix A, "Coordinate systems" the following commands are needed:

- Selection of active joints for standard motion
- Selection of active joints for reconfiguration
- Definition of coordinate systems

Program and data list management commands

To make the automatic mode as flexible as possible programs and data lists for programs have to be handled separately. Therefore commands are needed for:

- transfer of program or data list from control system memory to control system library,
- transfer of program or data list from control system library into control system memory,
- deletion program or data list from control system library.

Control system parameter commands

In addition to the command for setting acceleration, velocities, motion time, orientation, behaviour at via-points it should be possible

- to set control loop parameters which adapt the closed loop control to new conditions (e.g. new load)

- to override globally the velocities
- to set a global path offset

Input/output commands

Input and output commands via operator ports and process ports differentiate between input/output to the process and to the operator interfaces. Besides these input/output classes special attention has to be given to the construction of a flexible sensor interface because with EDITH investigations on sensoric motion control are planned.

Teaching

This functionality is known from industrial robot controls. It means on-line teaching with the manipulator in opposition to off-line teaching which is done on the Remote Handling Workstation. The on-line teaching is restricted to motion teaching.

Interfacing

The control system has to provide at least one virtual connection to ERWS with full functionality ("general interface") and one virtual connection for the operating interface. In addition one serial connection has to be available for an operating interface running on a portable host (handbox) for installation, tests, and maintenance.

Because one basic goal for the EDITH control system is to investigate control algorithms, a special test interface for closed loop parameter output (e.g. diagrams) during test runs has to be available.

Logging and backtracking

During operation all actions have to be recorded in a logging file in format. Especially in the manual mode this log-file has to be usable for backtracking. In automatic mode backtracking will be done on the basis of the program, logging is then reduced to recording the start of the program, its interruptions and ending. Logging behaviour has to be controllable.

Program execution control

This group of commands is needed for the automatic mode where a program is executed on the control system under supervision of the operator. If a program is started by the operator it has to be guaranteed that the manipulator and the supporting equipment is in a acceptable start postion and state. Automatic correction may be provided or operator help requested. The control system only has to provide these program execution control features and to guarantee some operational values. The whole complex of off-line programming is not part of the control system development.

Monitoring commands

The complete control system state has to be accessible for the handbox system and at a later stage for some super-ordinated workstation (ERWS). This means that data or groups of data defining the control system state have to be send via the corresponding interface upon request. In addition the control system may be commanded to send selected status information continuously or in case of status changes.

2.3 Operational Requirements

The fundamental requirements for the control system is to support minimization of the operation time. This means in detail to guarantee a specific dynamic behaviour of the EDITH system which allows for easy manual operation and automatic (preprogrammed) operation via the superordinated Remote HandlingWorkstation (Table 2.2).

2.4 Closed loop control Requirements

The fundamental requirement for getting an excellent dynamic bahaviour is the implementation of an advanced control scheme. Control system concepts of this kind are for example: inverse model based control or adaptive control. Implementation should be started with a standard decentralized PID control but the systems hardware and basic software must allow for an easy extension. The system should be layed out such that especially experiments concerning the dynamic behaviour and control system concepts can be performed.

Special attention has to be laid on experimental provision for sensor signal computations because especially with EDITH experiments with sensoric motion control are planned.

Requested parameters of the motion control of EDITH are listed in Table 2.2.

2.5 Implementational Requirements

The mapping of functions onto hardware is not fixed and has to be investigated for the specific EDITH control system. The following requirements should, however, be fulfilled:

- **Modularity**: Modular architecture for software and hardware is required for easy maintenance and upgrading. The architecture should be especially designed for an implementation in subsequent stages such that advanced features can be added as needed.
- **Implementation modules and stages**: The system should be divided into an equipment dependent and equipment independent part, to provide a certain degree of software reusability.
- **Extendability, Adaptability**: The system should be designed to allow for adaption of basic modules to control comparable subsystems or allow for subsystem changes with minor modifications.
- **Standardization**: Usage of hardware and software standards for communications, programming, data representation, system development and maintenance. A preliminary table of standards is shown in Table 2.3. The standards should be in accordance with the NCS standards, which are in discussion until now.

Topic	Limit
Repeatability (TU)	5 mm (constant payload)
Repeatability (WU)	2 mm (constant payload)
Hold (load difference: TBD kN)	2 mm
Minimal commanded change (motion step)	0.5 mm / 1.5'
Absolute positioning accuracy	100 mm (constant payload)
Maximal overshoot	zero
Time response	2 s
Minimum smooth (TBD) velocity	1 % of max.
Response to single motion command (dead time)	50 ms
Response to joystick motion command (dead time)	50 ms
Response to first motion command in loaded IRDATA program after START (dead time)	50 ms
Motion program loading (20 lines of code)	1 s
Response to first motion command in loaded program including download/execution (20 lines of code)	2 s

Table 2.2. Operational Requirements

2.6 Safety Requirements

Malfunctions and failures have to be reported to the next higher level of the control system. On the level of occurence a fault should be handled as far as possible to guide the system into a safe state. In case of a loss of the motion control system it must be possible to drive EDITH in an emergency mode directly from the drive control (see fig. 2.1).

Details have TDB.

2.7 Maintenance Requirements

Because EDITH is an experimental device, maintenance requirements are not of special relevance at this stage.

Topic	Requirement
Hardware	MULTIBUS II
operating system	iRMX
programming language	C
CASE-tool (Computer Aided Software Engineering)	e.g. X-TOOLS
program management (see: CASE)	as available
communication network	ETHERNET
communication protocol	TCP/IP
motion data format	close to IRDATA
control system cooperation and control	close to MMS
user interface management system (*)	TBD (at least extraction of functions into separate module)
window system (*)	X-WINDOW
user environment (*)	OSF/MOTIF

Table 2.3. **Requirements for implementation utilities**. This hardware, software and standards have to be used for implementation of the EDITH control system. Explanations to these standards are given in Appendix F, "Definition of terms"

3. Target system mechanics

3.1 General aspects

The ABT-part of EDITH, as shown in Fig. 1.5, is attached to a support structure instead of a trolley, which will be used with the ABS prototype for insertion of the ABT into the vessel.

The four rotational joints of EDITH next to the support structure (TY08 to TY11) are yaw-joints and allow movement of the transporter in the horizontal plane (cf. Fig. 1.5). This is the ABT-main-joint group. A typical arrangement of the drives for these joints is sketched in Fig. 3.1. The motors used are of the type DC brushless. Two or four motors are combined to drive a single rotational joint; the gear being used is a cyclo. The arrangement of motors may be used by the control system to preload the drives in order to reduce backlash and to increase stiffness.
Following the four yaw joints towards the end frame are a pitch joint TP01 and a roll joint TR02 for adjustment of the working position of the work units (cf. Chapter 1).

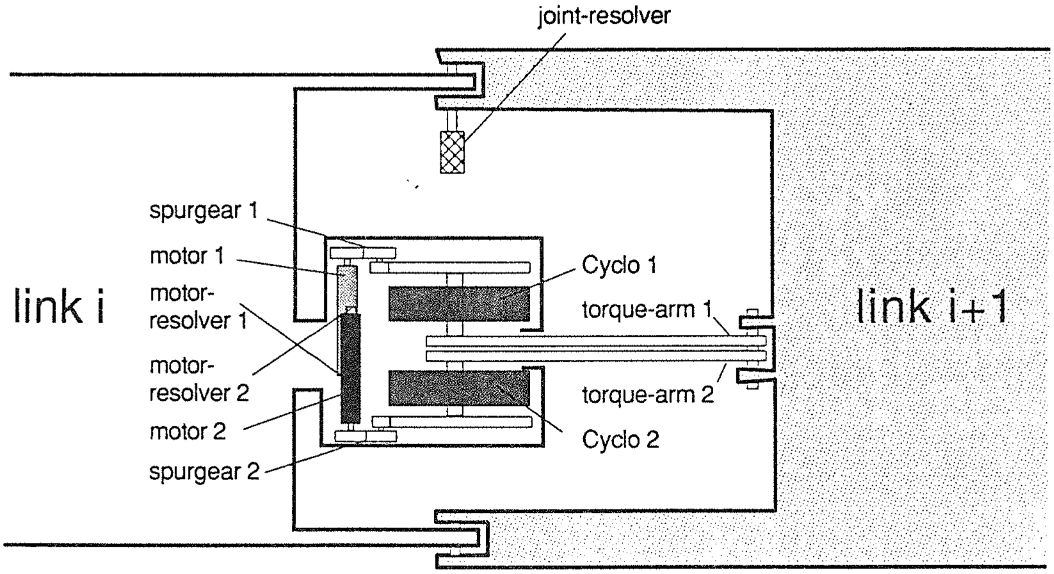
3.2 Joints and motors

The schematic diagram in Fig. 3.2 shows the arrangement of all of the joints of EDITH; the coordinate systems attached to each joint according to the Denavit-Hartenberg conventions are also shown in Fig. 3.2. Table 3.1 lists all of the EDITH-joints together with their identification.

group	identification serial number	symbolic name according to [1]	number of motors
virtual joint (see fig.3.2)	Z0	TL01	not implemented
main joint	Z1	TY08	4
main joint	Z2	TY09	2
main joint	Z3	TY10	2
main joint	Z4	TY11	2
aux. joint	Z5	TP01	2
aux. joint	Z6	TR02	2

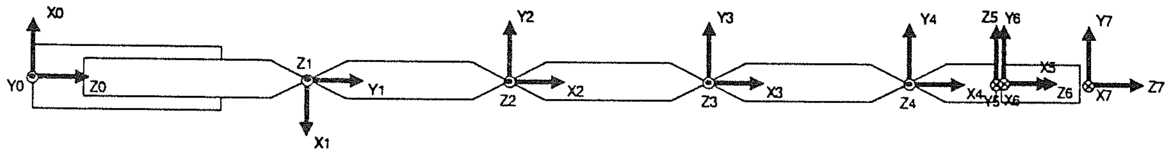
Table 3.1 EDITH joints (ABT)

Fig. 3.1: Drive unit scheme of EDITH



While the number of joints being implemented with the EDITH ABT is equal to 6 joints /14 motors for all ABT/WU combinations, the number of WU joints varies from 5 joints / 7 motors (MU positioning unit) over 5 joints / 8 motors (AHU) to 6 joints / 10 motors (DHD).

Fig. 3.2 Denavit-Hartenberg coordinate systems for EDITH-ABT (top-view)



Note 1: Z0 is a virtual prismatic axis; all real rotational axis and their corresponding coordinate systems K1 to K4 have to be attached in such a way, that K0 is taken into account. This measure is taken to allow for an inclusion of the real Z0 axis of the ABS without redefintion of coordinate systems.

Note 2: The direction of the Z axis of all rotational joints may be chosen to coincide with corresponding TARM definition

3.3 Instrumentation

The EDITH control system must be capable to produce individual set point signals for all 10 motors of the ABT-main-joint group (to allow for a controlled preloading) of the ABT; the number of set point signals for the WU's is 7 for the MU positioning unit, 7 for the AHU and 9 for the DHD; i.e. the control system must provide the corresponding number of analog output channels (cf. tab. 9.3).

To keep the number of power cables for the motors at a minimum, it was agreed upon to limit the number of power cables to the number which is necessary to drive the ABT/WU combination with the maximum number of motors, i. e. the ABT/DHD combination. The same procedure is followed to minimize the number of signal cabels from the joint position resolvers and motor resolvers. The solution of course requires, that identical types of motors and resolvers are used for different WU's, if they are connected to the same servo amplifier or resolver converter, respectively.

3.4 Work units

All types of work units will be attachable at the EDITH-ÀBT end flange. These are the

- divertor module handling device DHD
- manipulator unit MU
- and possibly an antenna handling unit AHU

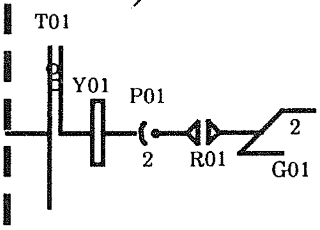
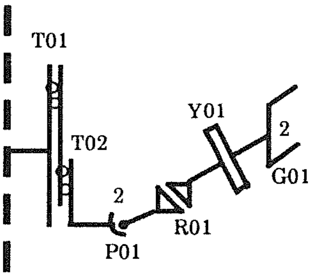
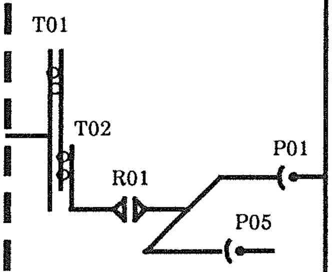
First drafts of these types are given to have an idea of the proposed work units. This does not mean, that all kinds will actually be built. Rearrangement of axis might also occur in actual designs.

The Edith motion control system must be able to control the respective axis of the work units in addition to the EDITH-ABT. Details are depicted in fig. 3.3. w.r.t. MU only the axis for positioning the manipulator pair must be controlled. Thus the manipulator positioning unit MU-PU, not the whole manipulators is included in fig. 3.3.

There are force sensors included in dedicated joints. For those joints being equipped with two sensors, there is one sensor dedicated to each direction of motion (push versus draw). Especially the grippers of the AHU and DHD are equipped with two force sensors each. Thus for the grip force restrictions may be posed on the respective control loops.

The meaning of the WU joint-names is symbolic

were T stands for telescopic
P stands for pitch
R stands for roll
Y stands for yaw.

ABT joints (no. of forces sensors)	WU of	type:	no. joints	no. servos	joints (no. of forces sensors)
		none	0	0	—
Z_1, (2), … , Z_6 (2)		AHU	5	8	T01, G01 (1) (2)
		DHD	6	10	T02, G01 (1) (2)
		MU-PU	5	7	

ABT
end flange line

Fig. 3.3 EDITH - Configurations (kinematic structures)

4. EDITH Control system Architecture

4.1 Implementation Aspects

In the process of designing the EDITH control system as a prototype of the ABS control system the JET-TARM control system was investigated as a possible implementation base . It turns out that the JET-TARM CS functions and components form a subset of the requested EDITH functions and components. The TARM HLCS may represent the kernel of a RH-area controller, the TARM LLCS a central equipment controller of the EDITH-area. To guarantee a higher flexibility of the LLCS, the hardware was replaced by a MULTIBUS II hardware and the implementation of the LLCS-software was based on an operating system (iRMX). With these changes the LLCS as well as the HLCS are open systems using standard interfaces such that software and hardware enhancements can be integrated easily. The disadvantage of using two different operating system (iRMX, VMS) was accepted, the implementation language on all levels is C.

The most important argument for basing the EDITH control system on the TARM CS is to facilitate the close cooperation with JET especially in the area of MMI (workstation development and enhancements) and advanced control algorithms. This justifies the disadvantages of the compromise.

4.2 Concepts and Facilities

The ABS-control system architecture, as planned for NET, reveals a hierarchical structure which in turn fits into the concepts of an overall control system architecture for NET remote handling, cf. Fig. 4.1 and [2].

Any EDITH control system architecture should be expandible and capable of being integrated into this concept.
As for the time no final concept for the NRWS [4] has been defined, the basic functions of the NRWS (man-machine interfacing, graphics based support) will be provided by an enhanced Graphics workstation as developed for JET-Tarm control. This ERWS is not part of the EDITH motion control system and therefore not subject of this document. Fig. 4.2 shows the EDITH motion control system architecture including the mapping of requested functions onto hardware. The basic TARM control system is described in [5].

Fig. 4.3 shows, how the EDITH control system architecture based on the TARM control system concept is mapped on real hardware (dashed lines indicate optional extensions or parts not belonging to the EDITH motion control system). The main difference between EDITH and the TARM control system is, that the low level control system is now implemented on a MULTIBUS II system, running on powerful CPU-boards (INTEL 80386 and up) with an application software being adapted to the iRMX-II-operating system.

The reasons for these modifications (migration to MULTIBUS II and iRMX) are the following demands:

- to allow for a step by step development of the final ABS control system, the EDITH control system must be easily expandible w.r.t. hardware and software. It must be an "Open System", i. e. a system being open to modifications by third parties and with a high degree of integrability
- Upgrade to higher performance should easily be possible, as the complexity of the final ABS control system is likely to increase. A demand for higher performance could be coped with either by distribution of functionality (thus creating "distributed applications") or by means of increasing the computing power.

Both of the above demands can be accommodated, if standards or defacto standards are used for operating systems, bus systems, communication interfaces, etc.

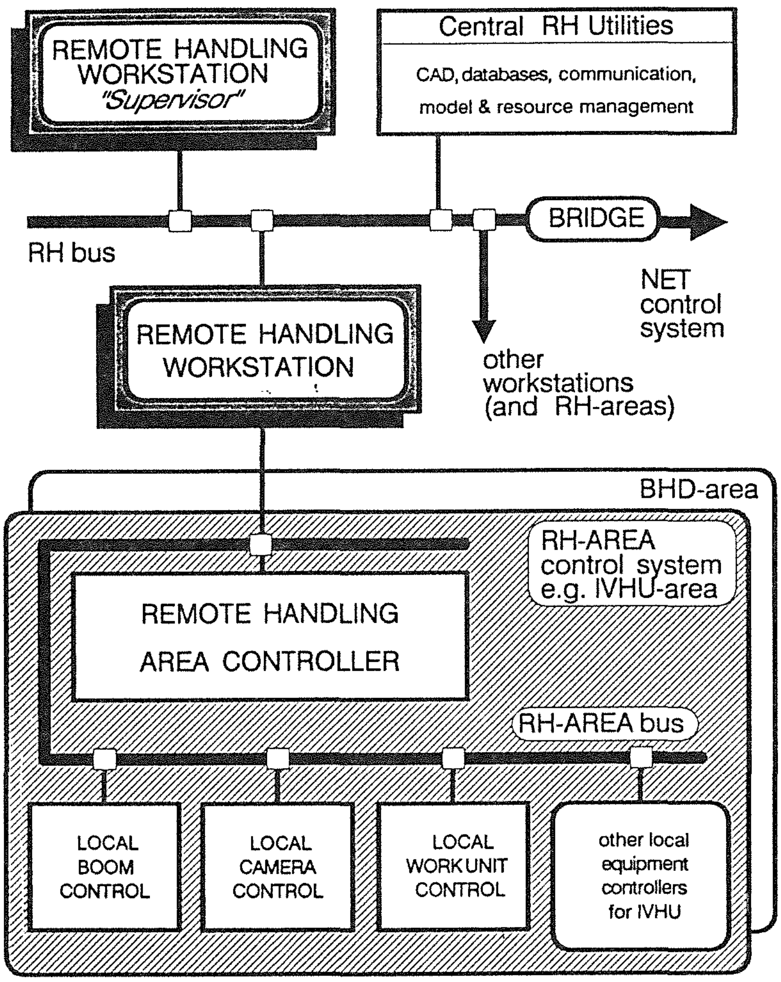


Fig. 4.1 Overall remote handling control system architecture for NET

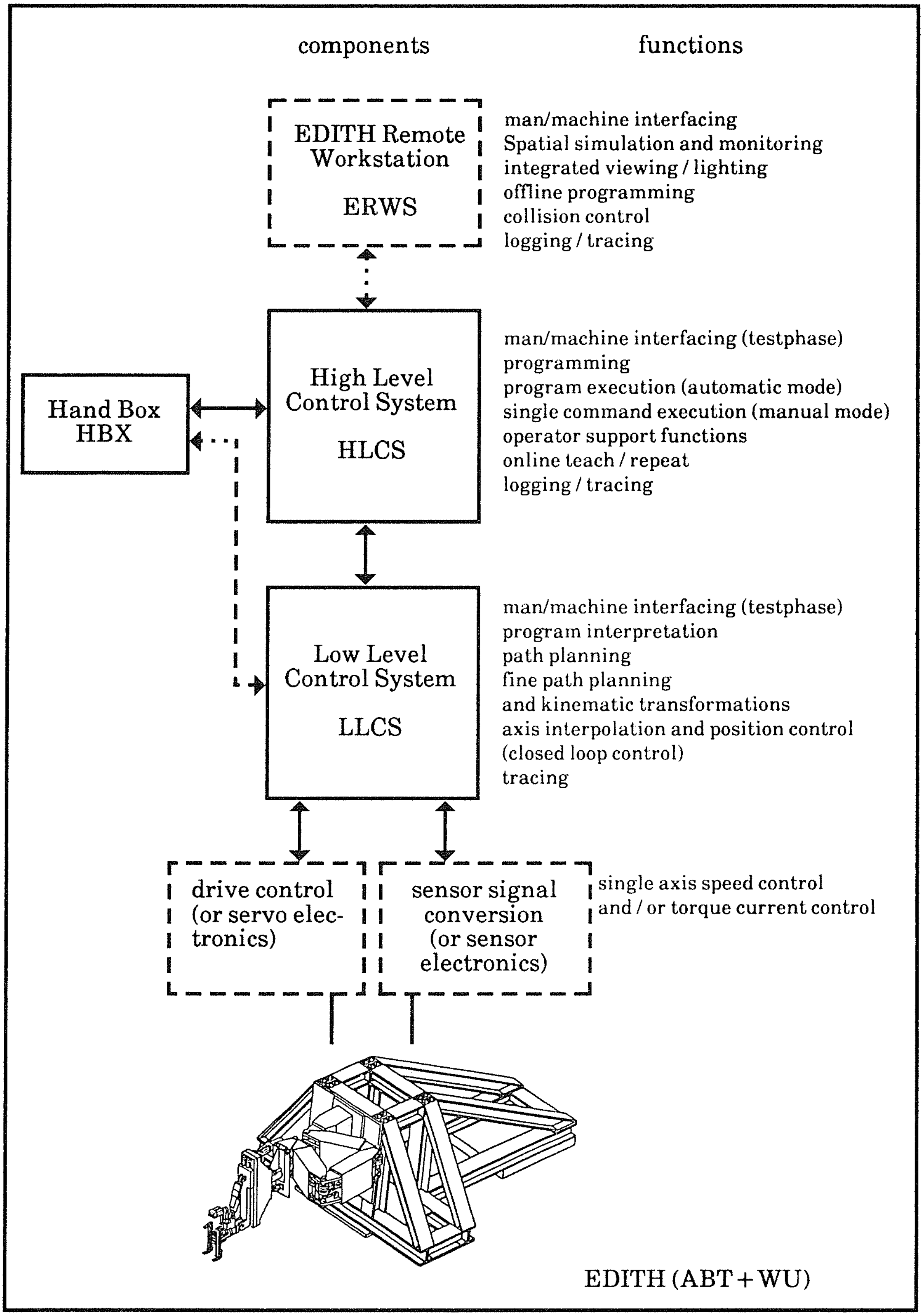


Fig. 4.2 EDITH control system architecture as resulting from the TARM control system

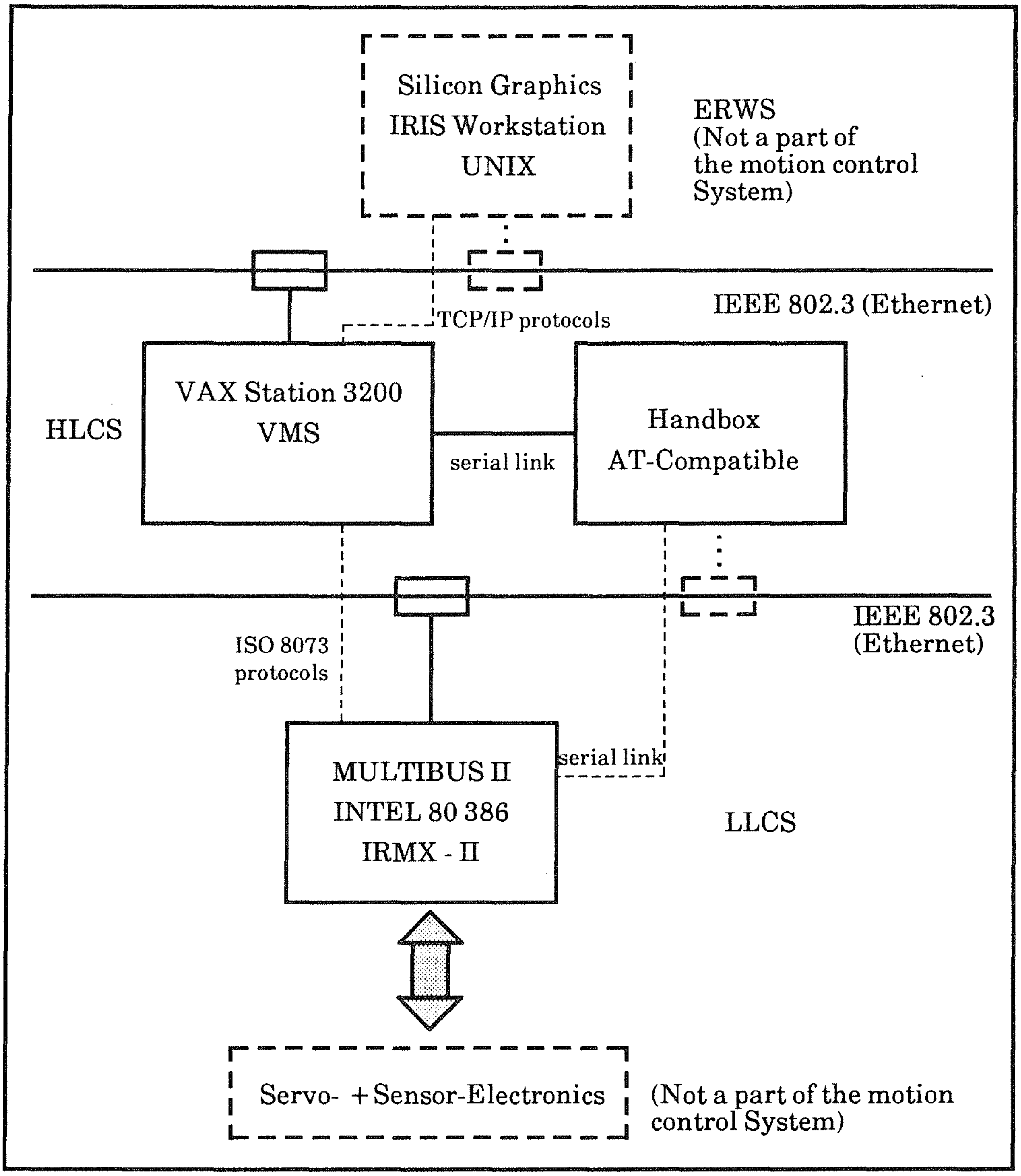


Fig. 4.3 EDITH Control System: Hardware Architecture

Finally, the effort that is necessary to derive the EDITH control system from the TARM control system is composed of two parts:

- the existing TARM control system software must be adapted to run under the operating system iRMX-II on a MULTIBUS-II system

  The choice of iRMX-II over iRMX-III has the following reason:

  iRMX-II is completely adequate for the required purpose and proven to be sufficiently reliable in many installations whereas iRMX-III is still too new. A later migration to iRMX-III will be possible with little effort.

- Since the target system EDITH is different from TARM w.r.t. its mechanics, kinematics, and control requirements, the existing TARM control system software must be modified and extended to take care of this. These software modifications extend on HLCS, Handbox and LLCS and include
  - different coordinate transformation (LLCS)
  - reconfiguration of joint positions without changing the position and orientation of the End-Frame (HLCS/LLCS)
  - tracing capability for evaluation of control system performance during test phases (LLCS)
  - Means to change control structures and parameters (LLCS)
  - torque control interface to servo electronics (LLCS)
  - guarantee of adjustable sampling time (path control and position control levels) (LLCS)
  - provisions for preloading of gear and advanced centralized control algorithm (LLCS)
  - provisions for additional sensors

4.3 Physical Layout of Control System and Test Site

Fig. 4.4 shows the EDITH test site, which is located in the KfK Remote Handling Lab. The test site has served formerly as a flaw which housed an experimental device for Uranium separation. The flaw is about 15 m deep and 10 m wide; if the EDITH boom is extended it will reach out of the flaw into the hall which is adjacent to the flaw.

The control room, as shown in fig. 4.4, is planned to be one level up. It provides space for the cabinets which hold the LLCS, the servo and the sensor electronics, and space for the HLCS (a VAX-Station) and the Handbox (HBX).

It should be mentioned, that the close neighbourhood of HLCS and LLCS is due to the convenience of testing, commissioning and experimentation, i. e. the purposes EDITH will be built for. On the other hand the structure of the motion control system should care for geographical separability of HLCS and LLCS for later application at NET/ITER.

It is important, that the cable length between LLCS and servo / sensor electronics is kept to a minimum. Therefore all of the cabinets are located next to each other. The maximum cable length between the control room and the boom will not exceed 40 m.

The ERWS mentioned earlier will be located in another control room not shown in fig. 4.4.

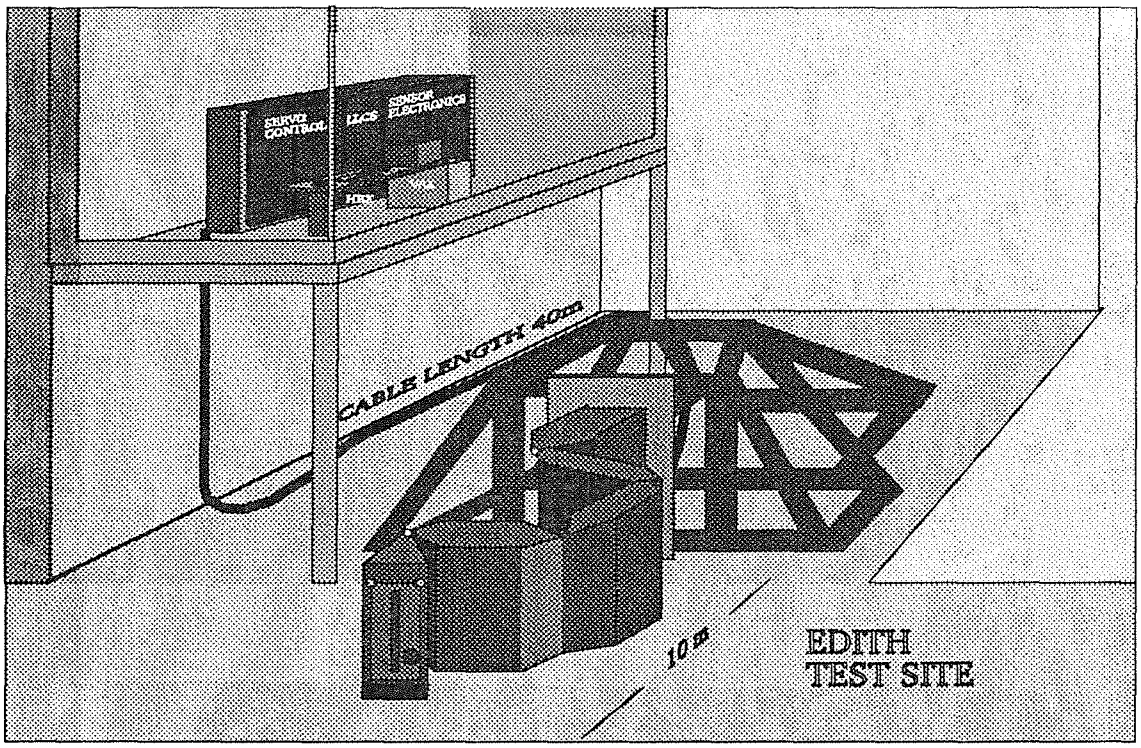


Fig. 4.4 EDITH test site

5. Hardware of the High Level Control System (HLCS) and Handbox (HBX) Subsystems

The hardware of the HLCS is required to support the VMS operating system (at least version V5.7) from DEC and the major requirements for the interconnection to the GWS via Ethernet and TCP/IP protocols and to the LLCS via Ethernet and OSI/ISO - 8073 protocols.

The hardware capacity w.r.t. storage is

- > = 8 MB main storage
- > = 150 MB formatted disk storage.

The HLCS should be able to integrate a bit mapped graphic terminal.

The connection between HLCS and HBX will be via RS 232 C serial line.

5.1 HLCS Hardware

At the present time 3 options are possible. All are based on Q-Bus.

Option 1: µ VAX II including

- 2 Ethernet-Boards one of which is an INTERLAN Board supplied with Intel's MVMSNET package. The other board is DEC's DELQA, capable of running TCP/IP.
- cartridge tape TK 50 or TK 70 including the respective controller board
- a serial line interface to the HBX which is compatible with the DHQ-11

Option 2: VAX station 3200 mounted in a BA 123 box.

- 1 Ethernet board DELQA from DEC capable of running TCP/IP and ISO/OSI - 8073 protocols concurrently. The software from DEC implementing ISO/OSI - 8073 is VOTS.
- graphical subsystem with 8 image levels
- TK 70 plus controller TQK 70 - AA
- DHQ - 11 compatible serial line interface

Option 3: VAX server 3300

- main storage expansion 8 MB
- DHQ - 11 compatible serial line interface
- TK 70 plus controller TQK 70 - AA
- 1 Ethernet board DELQA from DEC

For all options

- a standard VT 320 Terminal with an ASCII keyboard should be included
- a completely installed system w.r.t. to hard- and software has to be delivered
- sufficient documentation must be supplied

Discussion of the options:

Option	pro	con
1	same as for TARM HLCS same call-interface to LLCS (iNA 960)	performance is comparatively low for roughly the same price as the other options this option could cause run time problems if graphic applications are added old series
2	high performance including graphical subsystem	the call-interface to the LLCS has to be adapted to DEC's VOTS software, MVMSNET ist not needed for communication on the transport level (the INTERLAN-board is said not to work with VAX 3xxx)
3	high performance	the call-interface to the LLCS has to be changed to VOTS (see option 2) the addition of a graphic terminal is only by means of expensive VAX stations the price excluding graphic facilities is nearly the same as for option 2

Obviously option 2 is the prefered solution.

5.2 HBX Hardware

The HBX hardware must be capable to support the MS-DOS operating system for PCs. As the HBX should be easily transportable, a Lap Top is the best choice.

The TARM control system uses a Toshiba T3200. For the manual control two 3-D-Joysticks (Penny & Giles Type JS3) are necessary. An analog input board with at least 6 input channels and sufficiently fast conversion throughput is needed..

The HBX will be enhanced by two emergency off switches, which will be directly connected to the appropriate servo electronics part.

5.3 Other Components

The ethernet cabels, transceivers, terminators are defined to belong to the HLCS. This also holds for the RS 232 C cable & emergency off wires for the HBX.

6. Hardware of the LLCS subsystem

The hardware of the LLCS is in fact a complete Multibus-II computer and will provide the LLCS functionality as defined in the architecture (chap. 4) and in |7| chap. 8. Nevertheless provisions are made that this subsystem will fit into the overall EDITH Control System. These provisions are defined in detail in the following subchapters. Fig. 4.4 shows the geographical arrangement of the LLCS among the other cabinets. Due to technical limitations the workspace for the system engineer who is occupied with the development and testing of the LLCS functions must be located within an area of ~ 6 m diameter around the LLCS-cabinet. One of the most stringent technical limitations is the maximal length of the cable for the RGB-monitor. Other reasons are due to information indicators (LEDs, etc.) provided by LLCS-components.

In the following we give a description of the environment of the LLCS, provide implicit specifications about electrical issues which must be taken into account by the LLCS peripheral components, and specify the MULTIBUS-II components.

6.1 Cabinet for the LLCS

The type of cabinet has been chosen in accordance with the requirements for the servo- and sensor electronics to provide a uniform and compatible arrangement of cabinets as shown in fig. 4.4 and 6.1.

The completed LLCS-cabinet has to provide the degree of protection defined by IP54 (see chap. 6.7).

Cabinet type: Knürr (Munich) 1.217.736.3

including
- heat exchanger
- pulleys
- transport loops
- doors equipped with locks (same key)

The cabinet dimensions are approximately

Height: 1823 mm

Depth: 715 mm

Width: 600 mm

The heat exchanger capacity has been determined for a LLCS-system which allows for future extensions by additional boards.

Cabinet Front: The front of the cabinet must contain sockets

for
- pointing device (mouse)
- RGB-monitor
- keyboard
- 2 RS 232 C

The RS 232 C sockets should be 25 pin SUB-D connectors; pin convention according to DTE.

In addition, the front panel must contain at least two indicator lamps that can be used to indicate special LLCS-states. These lamps must be controllable of via the digital output boards. One of these lamps will indicate that the closed loop control cycle is active. The use of the other indicator lamp is t.b.d. A third signal will be available by a BNC-socket beneath these lamps. For the BNC-socket a TTL-compatible electrical signal level provided by an digital output channel will be sufficient. From this socket an external real time counter may be fed.

It might be necessary to include sockets and lamps in some metal sheet if the acrylglass door does not permit their integration. In this case the metal sheet must not be higher than approx. 8 HE. Otherwise the LEDs of the Multibus-II boards (above this sheet) or the optical alarmsignal of the heat exchanger (beneath this sheet) would be hidden (see chapter 6.3).

In either case, the sockets are recommended to be placed in the lower right part of the door. It must be possible to open the door without being forced to disconnect any connectors.

Side walls: No plugs, no connectors etc. because the cabinets will be set up side by side as shown in fig. 6.1.

Back: The back side of the LLCS cabinet will be equipped with

- 12 sockets for process signals
- 1 ethernet socket
- power supply cable.

Again it must be possible to open the back door without being forced to interrupt processing. It's recommended to place the sockets in the immovable 8HE-metal sheet that belongs to the heat exchanger. Details according the sockets for process signals are contained in chap. 6.2.

6.2 Cable arrangements

This chapter will only discuss those cables which are needed for the process signals. For all other cables standards apply.

Fig. 6.1 shows the arrangement of control cabinets and the cables for interfacing with each other. For all cables the socket/plug-type used will be AMP's circular plastic connector, shell size 23, pos. 57. All cables (including the plugs) to be supplied must contain coded plugs to avoid unintentional exchange of cables.

Three cable groups will be necessary. The

t-group for the ABT-servo-electronics

w-group for the WU-servo-electronics and the

e-group for the sensor-electronics.

The lenght of the cables for the t- and e-group will be approx. 1,5 m except for e1 which must be 1 m, and the length for the w-group will be approx. 2,3 m.

All cables except for e4 are to be supplied and documented (pin assignment, mechanical coding scheme to avoid exchange). The cables & plugs are described by table 6.1.

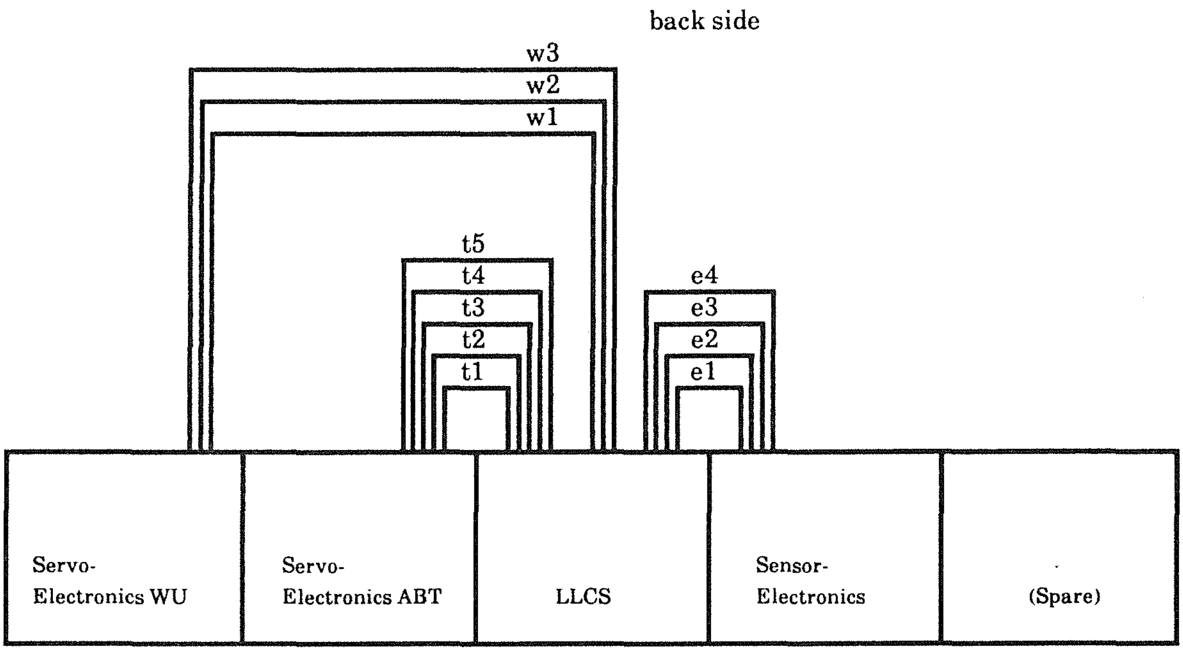


Fig. 6.1: Arrangement of control cabinets for the EDITH-Control-System (top view), Cable Connections

Cable-ID	plug-ID LLCS	function
t1	plt1	for servo resolver bus
t2	plt2	analog in/out servo electronics ABT
t3	plt3	binary in servo electronics ABT
t4	plt4	binary out 1 servo electronics ABT
t5	plt5	binary out 2 servo electronics ABT
w1	plw1	analog in/out servo electronics WU
w2	plw2	binary in servo electronics WU
w3	plw3	binary out servo electronics WU
e1	ple1	for joint resolver bus
e2	ple2	analog out 1 from sensor electronics
e3	ple3	analog out 2 from sensor electronics
e4	ple2	spare

Table 6.1: Cables and plugs for interconnection to the LLCS

6.3 Internal layout of the cabinet

The fig. 6.3.1 shows the configuration of the components within the cabinet.

Between the MULTIBUS-II I/O-Board (analog and digital I/O-boards respectively) and the connectors on the back side of the cabinet there must be a crossbar switch. It will be used for switching the wires as needed.

To be easily accesible, the crossbar switch must be fixed near the circular plastic connectors but not on the back door of the cabinet.

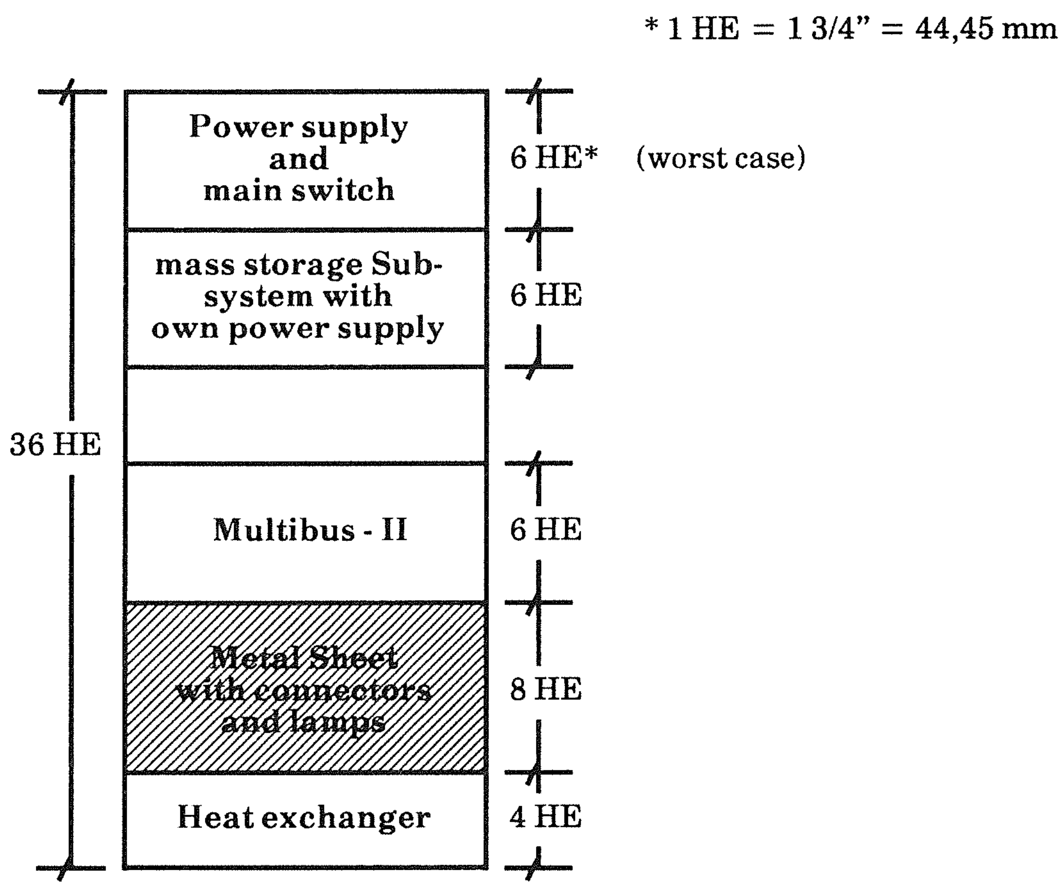


Fig. 6.3.1 "Front view"

6.4 The Multibus-II components

The Multibus-II components (see fig. 6.4.1) are housed in a chassis respectively card cage (19") with a board capacity of 20 slots, not all of them will be used (spare).

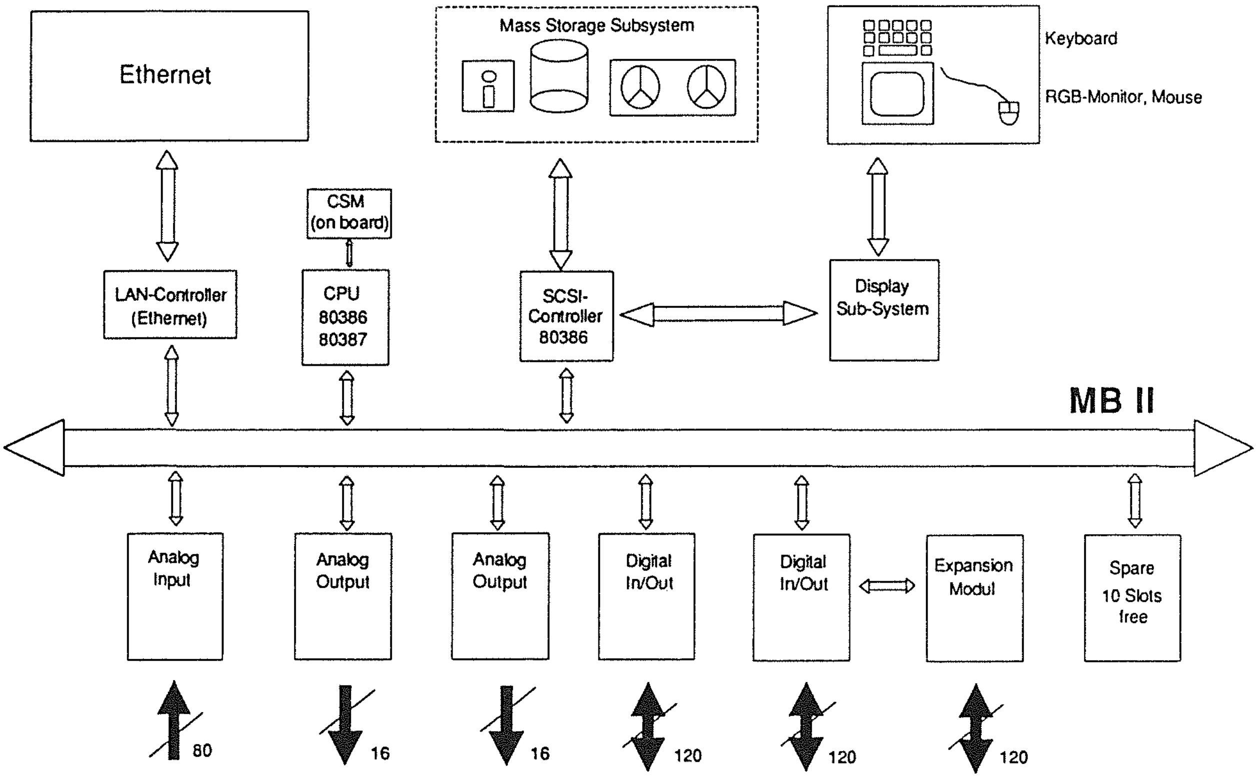


Fig. 6.4.1: Hardware Architecture LLCS

The micro computer system consists of

- original Intel-Boards as far as possible:
  - 1 80 386, 33 MHz CPU incl. 4 MB and CSM-functions
  - 1 4MB-SCSI-Controller for mass storage
  - 1 Ethernet LAN-Controller
  - 1 iSBX 279 Display Controller

- Multibus-II I/O boards need not to be original Intel-boards. A sufficient number of input/output channels have to be provided:

	Channels	
Analog-In	80	(speed 5.2 µsec)
Analog-Out	32	
Digital-In/Out	360	

The specifications of the electrical signal characteristics of the analog-in- and analog-out-channels must be taken into account by the LLCS peripheral components described in chapter 7. Where necessary the digital I/O channels should be opto decoupled.

6.5 Mass storage Subsystem

The mass storage subsystem is housed in the INTEL peripheral module SYP 342 including power supply for the storage components. This peripheral module is mounted on telescopes and must be equipped with the following storage components:

- 300 MB hard disk
- 1,2 MB floppy disk drive (with capability to support Intel-Format)
- 640 KB floppy disk drive
- Tape drive

The power supply for the complete mounted peripheral module is connected to the main switch (see chapter 6.6.1).

6.6 Other components

The system software for the Multibus-II system (iRMX-II) excluding process-I/O will be provided either on tape or floppy disk.

6.6.1 Main switch

The main switch which is located close to the power supplies for the Multibus-II card cage and activates the following circuits:

- the power supplies for the Multibus-II (+ 5 VDC and ± 12 VDC)
- the power supply for the mass storage subsystem
- the heat exchanger

Thus the main switch can be locked by the front and back doors of the cabinet.

6.6.2 Power supply

The power supply for the Multibus-II card cage must be dimensioned in such a way that 3 additional CPU boards and 4 additional process - I/O-boards can be supplied.

Requirement:

+ 5 VDC / 125 A	power supply output
+ 12 VDC / 8 A	power supply output
- 12 VDC / 8 A	power supply output

Recommendation:

1. At present it is possible to get a Multibus II-chassis equipped with the suited power supply unit. In this case a switchable socket line must replace the main switch.
2. + 5 VDC / 125 A 750 W power supply ESP 815125 from ELBA (Oberhausen)

   Because it may be a problem to find a ± 12 VDC power supply with the requested specifications, it must be possible to connect two power supply units in parallel.

   It is recommended to order a custom built 19"-rack with the complete (parallel-) connection of the power supply units incl. the main switch.

6.6.3 Color graphic display

The color graphic display, a RGB-monitor, is connected to an iSBX 279-module, which allows in addition for the attachment of a keyboard and a mouse.

6.7 Basic Requirements

Protective measures: application of standard IP54

- complete electrically shock-proof
- dust-proof; dust accumulation is allowable, but the quantity must not expose the function of the device to danger.
- splash-proof, w.r.t all directions.

IP54 is the usual standard for applications in an industrial environment. Higher protective systems providing protection against inundation or dust-tight are not required in our application environment.

Environment Specification

Radioactivity	: negligible		
Operating:	Temperature	:	0° C to 50 ° C
	Relative Humidity	:	10 % to 90 % non condensing

Storage conditions (all component inactive):
Temperature : -40° C to +70° C
Relative Humidity : 10 % to 90 % non condensing

Quality of Power Supply

It is recommended to use a hum eliminator to protect the sensitive Multibus devices.
Doing so, it is important to know that a possibly existent overcurrent tripping can be activated during the switch-on moment. To remove this effect, the hum eliminator has to be put in front of the overcurrent tripping (seen from the main man-circuit).

7. Interfaces of Servo- and Sensor-Electronics

The distinction between Servo- and Sensor-Electronics, as indicated in chap. 4, is pragmatical in a sense that in the case of sensor-electronics an own cabinet is meant to include all the sensor equipment not directly needed in conjunction with the servo-electronics.
The servo-electronics comprises mainly the servo-amplifiers including some safety logic components and other electrical equipment. Thus the AC-servo-amplifiers include resolver- to digital-signal converters like AMD's 2S80 needed for electronic commutation. This chip also delivers an analog velocity signal. Also range switches can be addressed as simple sensors. But range switches are defined to be part of the servo electronics.
The electro-mechanical interfaces will be by AMP circular plastic connectors at the back side of the cabinets.

7.1 Interface of Servo-Electronics w.r.t. Motion Control System

The main constituent part is the servo-amplifier. In the case of EDITH the type FSR AC S from ASB has been selected.

For the EDITH-ABT 14 servo-amplifiers are needed, 10 of them for the EDITH-ABT main joints.

The servo-amplifiers for the work units, as described in chap. 1, will be contained in a separate cabinet. 10 amplifiers will be used to drive one out of 3 types of work units at a time.

7.1.1 All Servo Amplifiers

Each of the 24 servo-amplifiers provides the following inputs and outputs:

Analog-Inputs $\subseteq$ analog outputs of motion control system (exception is S7, see tab. 9.3):

1 - either for set point current (this is the usual case, thus an easy means is given to limit the maximal torque of a drive by limiting the set point current)
or for set point velocity (see table 9.2). If the interface for set point velocity is used, the velocity control loop is realized by a hardwired control loop on the ABS servo amplifier.
characteristics:
- 10 V .... 0 .... + 10 V differential

(1 - another analog input is optional but will not be used)

Analog-Outputs = Analog Inputs of motion control system:

1 - velocity signal for rotor velocity
(single ended)

Binary-Inputs ⊆ Digital Outputs of motion control system:

1 - for activation of servo amplifier (≙ enable servo)
characteristics:
+12 V .... +28 V opto decoupled

Binary-Outputs ⊆ Digital Inputs of motion control system:

1 - Status : ready (if there is no warning)
28 V; 25 mA opto decoupled

1 - warning; warning indicates, that the amplifier will turn off power in 2 seconds
because of overload (I^2t).
characteristics:
28 V; 25 mA opto decoupled

7.1.2 Brakes

Each motor will be eqipped with a safety brake. In total the EDITH-Motion-Control System has to address 24 motor-brake-combinations at a time. 10 lines will be multiplexed again for the work units. Thus the brakes are lifted by 24 digital inputs. Details remain to be defined like time constants and voltage (probably 24 V).

7.1.3 Group Controls

There are different controls which are not applying to each single axis but are applying to a complete group.

7.1.3.1 EDITH-ABT-Group

Status (=digital out ≙ digital in of motion control system):

1 control supply ok } make sense only if ABT-servo-control is not in emergency-off-state
1 power supply ok }

1 emergency-off (activated by manual intervention)

Watchdog (digital in ≙ digital out of motion control system):

1 enable watchdog entry

1 I am alive entry

The function of the watchdog is to disable all servo amplifiers of the respective group if

- watchdog has been enabled

and

- fixed time period has run down (≈ 50 msec) within no 0 → 1 input has been detected at the "I am alive" input.
  In case of 0 → 1 the watchdog timer is set again.

7.1.3.2 WU-Group

For this group the same holds as for the EDITH-ABT-Group. Additionally

1 Control Signal to reset the amplifier group in the case of undocking/docking is necessary.

7.1.4 Joint related interface

Each joint will be equipped with mechanical range switches. Details remain to be defined. Thus

- left/right switch information

must be considered and displayed by the motion control system. But the semantics still have to be defined. At the present state the motion control system need not to do any actions e. g. STOP a distinct joint or a group of joints. The mechanical range switches are assumed to work directly upon a distinct joint or a group of servo amplifiers. The motion control system will detect this by secondary effects e. g. the status might be "not ready" but the respective servo has not been disabled by the motion control system and there is no emergency-off status information.Altogether for 6 joints for EDITH-ABT and for (maximum) 6 additional joints of a work unit 24 information channels have to be provided.

7.1.5 EDITH-ABT-Main-Amplifier Sub Group

There are 10 servo amplifiers for the EDITH-ABT main joints. As these motors are planned to be controlled in a special way later on, position information of the respective motor rotor will be provided by a separate bus system (we will call it the servo resolver bus). First of all the servo resolvers are used for the electronic commutation of the brushless electric servo motors. The structure of this bus system will be as follows:

- 5 address lines to select the amplifier
- 14 data lines for rotor position information
- 2 control lines to implement a hand shake procedure.

Details remain to be defined.

Thus 15 digital outputs
6 digital inputs

should be sufficient.

The part of the motion control system w.r.t. this interface is just to read all these 10 rotor position values each control cycle and to provide a defined internal interface for the main LLCS - CPU.

7.1.6 Other Interfaces of the Servo-Electronics

At the present state

1 super-emergency-off is planned delivering the respective status.
The super-emergency-off will work on all subgroups and all subgroups of other equipment not defined yet.

To support the docking/undocking of work units, status and control signals have to be provided:

3 binary signals for encoding the specific type of work unit

1 signal to indicate successful mating

1 control signal for activating a component T.B.D.

This docking support feature is defined here to belong to the servo electronics as there might be some logical interrelation with the possibility to enable the work unit servo amplifier group.

7.1.7 Summary of Channels from the Motion Control System to the Servo Electronics

Channel type	No. for the ABT-group		No. for the WU-group	other servo component
analog out - 10 V ... 0 ... +10 V	14	set point	9	----
		Σ = 23		
analog in - 10 V ... 0 ... +10 V single ended	14	velocity	10	----
		Σ = 24		
digital out	14	activate servo	10	
	14	lift brake	10	
	2	watchdog	2	
	6	servo resolver bus	--	
	--	reset	1	1 docking support (e.g. unlock clutch)
	----- 36		----- 23	
		Σ = 60		
digital in	14	ready (state)	10	
	14	warning	10	
	1	group control supply	1	
	1	group power supply	1	
	1	group emergency off	1	
	15	servo resolver bus	--	1 super-emergency-off
	12	range switch	12	
	----- 58		----- 35	3 WU-encoding 1 mating OK
		Σ = 98		

7.2 Interface of the Sensor-Electronics w.r.t. Motion Control System

7.2.1 Joint Resolver System

The most important sensors needed for position control are the joint resolvers. The EDITH-ABT-Main-Joints will be equipped with multi-turn systems from Gerwah's RMA/GAG. All other joints including the work units are equipped with single resolver systems.

All positions are absolut.

One should remember that the servo resolvers will not deliver absolut joint positions. Futhermore the joint resolver values won't be impaired by backlash.

Again the resolver converters for the work unit joints will be "multiplexed".

In total 4 multiturn resolver systems RMA 19 for EDITH-ABT-Main-Joints

2 single turn resolver systems EDITH-ABT-auxiliary-joints

6 single turn resolver systems will be used for a maximum of 6 work unit joints

All information of the 12 joints will be made available by the joint resolver bus system.
The bus system will be structured as follows:

- 5 adress lines for addressing up to 32 converters
- 23 data lines to provide position information (either 19 or 16 bits) and direction information (1 bit)
- 2 lines to implement a hand shake (1 input, 1 output)

7.2.2 Other Sensors

This is a group of sensors which have to be read in and displayed by the motion control system but which have in this spec. no other effects.

16 analog channels ($\pm$ 10 V) indicating distance information of ultrasonic range sensors

3 analog channels ($\pm$ 5V) indicating information of inclinometers

6 analog channels ($\pm$ 10 V) indicating information of acceleration sensors

7.2.3 Force Sensors

These sensors have to be read in at the frequency of the position control loop, the values must be monitored against crossing upper/lower limits (to be programmable in the motion control system) and have effects on the joint control loop T.B.D. (initially to switch off the servos).

The values have to be displayed by the motion control system as well.

12 analog channels, 2 for each of 6 joints of the ABT will be provided

3 additional channels are devoted to force measurements of WUs

7.2.4 Summary of Channels to be provided by the EDITH Motion Control System for the Sensor-Electronics

Analog-Outputs:	0	
Analog-Inputs:	12	(velocity of joints)
	16	(distance)
	3	(inclinometers)
	6	(acceleration sensors)
	15	(forces)

	Σ 52	
Digital-Outputs:	6	(joint resolver bus)
Digital-Inputs:	24	(joint resolver bus)

8. HLCS - and HBX-Software

Both systems must provide the necessary system-software for general purpose use and application dependent software development.

8.1 System-Software

8.1.1 System-Software HLCS

The HLCS-Software is implemented upon DEC's VMS operating system. The application Software is written in C.

Thus

- VMS Version 4.7 or up (e. g. V 5.2)
- C Compiler plus Debugger, Linker
- DEC-Windows
- depending on the final choice of the Ethernet-Controller to the LLCS
  either
  - VOTS from DEC or
  - iNA 960 included in Intel's MVMSNET
- appropriate documentation
  (for VMS an extended documentation kit is needed)

will be needed.

8.1.2 System-Software HBX

As the HBX is essentially a PC, the only requirement is for the standard operating system

- DOS Version 3.3
- appropriate documentation.

8.2 Application Software

The application software is the motion control software which is dealing with user input commands, coordination of actions, communication between the respective control system computers, data management, data conversion and finally presentation of states and results to the user. The functionality as well as the input / output formats and its implementation will be that of the TARM-Control System for JET. The TARM-Control System has been developed by ISRA Darmstadt. As the functionality is described in |5| and |6| only a short sketch of the functionality realized by HLCS and HBX is given. Emphasis will be put on the necessary differences due to the mechanical properties of EDITH.

Fig. 8.1 shows the operational functionality of the TARM-Control System w.r.t. possibilities to command movements. Command sets for monitoring functions and parameter handling are not included in fig. 8.1. Via parameter handling functions one can specify i.g. servos loop parameters, and other attributes like velocity, acceleration, fly point tolerances (fly point ≙ via point).

Motion commands issued by using a joystick can not be recorded. Therefore in the Recording Submode-, Command Submode- and Insert Submode-states Joystick Operation is not possible.

Joystick Control means defining velocities and their directions respectively. Velocities refer either to joint or to cartesian space. The selection of joint or cartesian space is by means of the ASSIGN command which defines additionally a mapping between either joints and one of two joysticks or of the so called POR (point of reference) to one of two joysticks. The POR is a fictive point which is defined to be fixed relativ to joint A4 in the case of TARM. In the case of cartesian definitions further information is needed by the control system. This information can be supplied interactively by the operator. SET__Elbow will specify which solution in case of multiple solutions or strategies will be taken to achieve a cartesian motion.
Freeze__POR__Point__i will define 3 joints (namely the remaining three ones of a set of four) responsible for achieving cartesian motion.
The control coordinate system (CCS) may be selected by POR__Control__{world/tool}. The CCS is the (conceptually) fixed coordinate system, to which momentary velocity commands for the POR refer to. In Fig. 8.1 these commands are only included in the Command Level state. For the sake of simplicity of the fig. they have been omitted in the states, where "Joystick-Control" is possible too. Not included other motion related commands are the gentle stop HALT and the tough emergency stop STOP.

In fig. 8.1 MOVE__{POR/AXIS}__VIA stands for the two commands MOVE-POR and MOVE-TARM. The main difference between MOVE-AXIS and MOVE-Joint is that MOVE-Joint requires numerical joint values and MOVE-AXIS needs symbolic joint parameters. The reason is that MOVE-AXIS is used for recording purposes in contrast to MOVE-Joint.

This can be seen in Fig. 8.1 : MOVE__{POR/AXIS} is valid only in the substates

- Recording Submode of Teach Mode
- Insert Submode of Edit Mode.

In the Teach Mode, all commands are recorded including the appropriate dynamic attributes. Point values and intermediate point values are included by means of HERE which includes these values together with its symbolic names into a table. This information is sufficient for repeating motion sequences in the Repeat Mode. Instead of just repeating, one can also edit these so called sequence files in the Edit Mode. In the Edit Mode one can modify such a sequence by deleting and inserting commands. Other means for editing are UNDO and STEP__MODIFY. UNDO discards the last command (MOVE or PAUSE). STEP__MODIFY will execute the next MOVE command and allow modification of all referenced points respectively. Recorded commands form a completely ordered sequence. By means of SKIP N the motion starting command may be selected. Alignment between current TARM position and starting position is normally by operator control using joystick or MOVE__Joint commands. It is interesting that the parameter N of STEP in the Command Submode may be negative, thus a motion sequence will be gone backwards.

The functionality of the motion control system is described in chapter 8, i. e. in conjunction with the HLCS- and HBX-application software. It should be clear, that a great deal of the implementation is in the LLCS too of course. This refers for example to the respective coordinate transformations and path planning tasks.

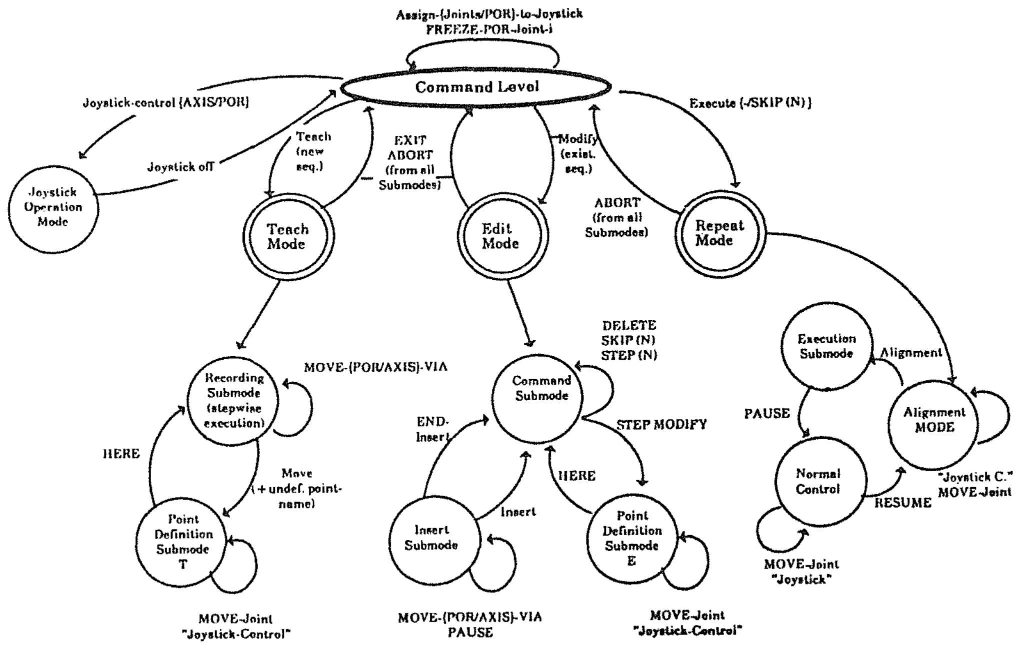


Fig. 8.1 Operational Functionality of the TARM Control System

8.2.1 Differences and Extensions of the Edith control System w.r.t. the TARM-Control-System

First one should mention that the part of the TARM mechanics starting with joint A2 which is a prismatic joint, is conceptually foreseen in EDITH, but will not be realized mechanically. Nethertheless the numbering and naming scheme (cf. chap. 3) is as if A2 was present. The further TARM-joints responsible for cartesian (planar) movements are the yaw joints A3, A3B and A4. In the EDITH Control System terminology these joints are named Z0, Z1, Z2 and Z3 respectively. The only difference is for Edith to include a further yaw joint Z4. Thus the command

FREEZE_POR_JOINT_i

has to be extended to freeze a second joint j to obtain a nonredundant kinematic chain.

An additional command required for EDITH is the RECONFIGURATION command. This means a combination of joystick control and implicit cartesian control. The semantics is as follows:

- all four yaw joints take part in the operation
- one of the four yaw joints is selected and mapped to a joystick and joystick-DOF (DOF = degree of freedom) i. g. "turn"
- the operator controls this joint in velocity axis control mode
- the motion control system controls the additional 3 joints in a fashion, such that the end flange remains fixed w.r.t. the world coordinate system (K0)
- in the case of multiple solutions the same specifications should be valid as for POR-Control
- this command is primarily to be classified as a joystick motion-command and thus applicable in all states where a joystick motion-command is valid (cf. Fig. 8.1)
- the integration in the TARM command syntax could be as follows
  - with an ASSIGN-Joints-to-joystick only one axis x ε {Z1, ... , Z4} must be selected
  - the command JOYSTICK-CONTROL contains RECONFIG plus joystick identifier (number) as additional name parameter value and parameter respectively
  - the other "joystick-joints" should be tested to be disjoint to the axis set {Z1, ... , Z4)
- the internal telegram formats should be conformand with the existing scheme.

Another feature of the EDITH motion control system which is different from the corresponding TARM feature is the docking of work units at the end flange. A DOCKING command is available in the TARM control system but the semantics are different:

- three different types of work units to be controlled (MU-PU, AHU, DHD) may be attached one at a time
- the physical servo electronics and physical sensor electronics and its respective cables will be "multiplexed".

This involves internal management operations to reflect the actual configuration. Typical operations would be to switch servo loop parameters, joint parameters, velocity attributes, input checking constraints and the like.

The motion command specifications for work units will be only at the axis level. Nevertheless these should be part of the teach sequences. The kinematics of the work units are described in chap. 3. More details of instrumentation, motors etc. is given in chap. 7 and 9.

This kinematic state change has to be reflected in the command execution subsystem of the HLCS as well as in the HBX including the state description in the respective screen windows. Other modifications in the state or system state display refer to different or additional servo states and display of additional sensor information (ultrasonic range sensors, force sensors, inclinometers).

If not already contained as a part of the functionality of the TARM Control System, a simple switching function including a switch number as a parameter should be available and integratetable into a teach sequence file. Thus one could automate work unit exchange.

9. Low Level Control System Software

The HLCS and the Low Level Control System (LLCS) of EDITH could be roughly characterized as a industrial robot controller combined with a part which is devoted to manual mode operation. According to this the main functions of the LLCS are the execution of single motion commands (manual mode) and the execution of complete motion programs (automatic mode).

As the EDITH-specification is based on the JET-TARM-specification |5| in the following only those aspects will be presented which differ from the TARM-specification.

It should be mentioned at this point, that all axis related safety controls such as software range switches, maximal deviation from the set point as well as maximal speed have to be carried over from the TARM software.

9.1 Software adaptation

The complete software has to be converted to run on MULTIBUS-II/iRMX-II.

9.2 Coordinate-transformations

The coordinate transformations have to be adapted to the kinematical design of EDITH (see Fig. 3.2).

9.2.1 Base coordinate system

The base coordinate system (BCS = K0 in Fig. 3.2) serves as general reference. Moving EDITH in cartesian coordinates, all nominal velocity values have to be transformed relative to the BCS.

9.2.2 Joint coordinate system

Each joint of the kinematic chain has its own coordinate system defined according to the Denavit-Hartenberg conventions. These coordinate systems are defined in Fig. 3.2. We assume that the coordinate systems are compatible with TARM Joints A2, ..., A4, otherwise Fig. 3.2 has to be redefined.

9.2.3 Control coordinate system

The control coordinate system (CCS) is a special cartesian coordinate system to describe motions. This coordinate system may be attached to the manipulator or to the environment.

All positioning commands which have to be interpreted are relative to the CCS. In the TARM control system the CCS is either "world" or "tool".

9.2.4 Manipulator reference frame

The manipulator reference frame (MRF) is a coordinate system representing the manipulator during motion. The origin of the MRF is called manipulator control point (MCP). MRF resp. MCP corresponds to the tool coordinate system resp. tool center point in robotics. In the TARM control system the POR is coincident with MCP.

After defining the CCS an operator may move the MRF or the MCP relative to the CCS.

9.3 Reconfiguration

It is requested to have the possibility of reconfiguration. Reconfiguration is a special type of joint motion control, where some joints are controlled by the control system and the others directly by an operator (cf. chap. 8).

9.4 Trace-function

A trace-function has to be implemented to record

- set positions
- actual positions
- actuating values (motor torques or currents)

for a sufficient time period with informations for each sampling.

9.5 Position control

Position control is a vital part of the motion control system. The position control has the task to convert as exactly as possible and without delay the desired values given for example from the pathplanning-modul into a real motion. The effect of disturbances, e. g. force impacts, have to be compensated.

9.5.1 Control structure

The position loop for each axis will be closed in software, using a programmable PID controller with velocity feed forward (see fig. 9.1).

As EDITH is an experimental device as mentioned in chapter 1, it should be easily possible to implement advanced control algorithms like Inverse Model techniques [19] or adaptive control schemes [20].

All control parameters have to be stored. The control parameteres of the work units have to be changed automatically corresponding to the selected work unit.

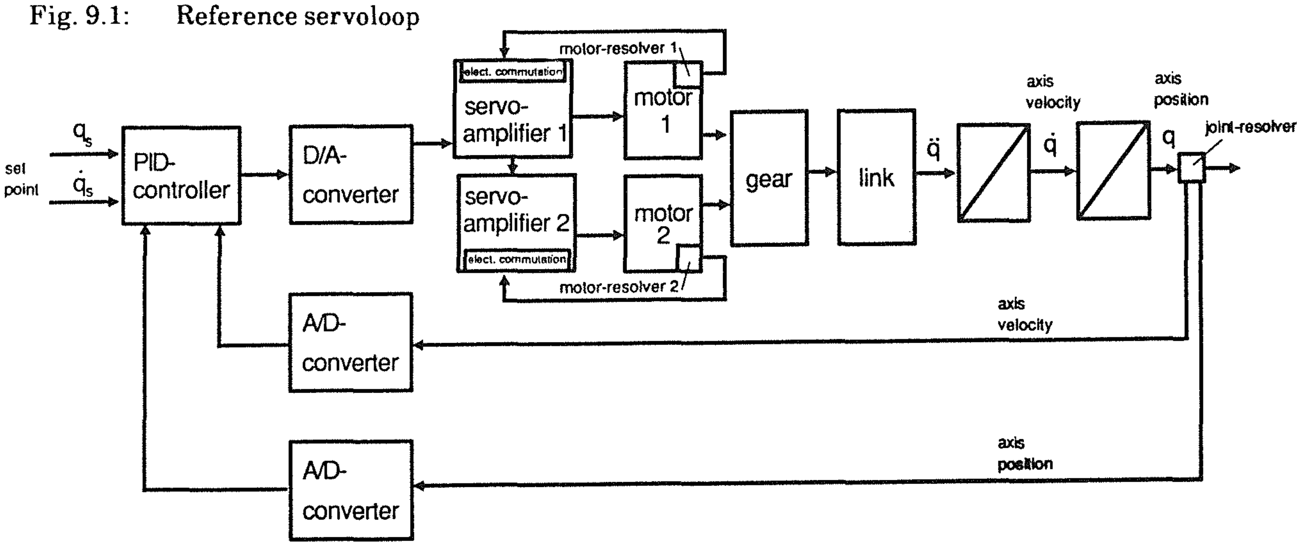
9.5.2 Sampling time

The control loop sampling time must in a first step not exceed 20 msec. It should be possible to set the sampling time by the system operator. A sampling time of 20 msec. is sufficient for position control of EDITH, also in the context of advanced control algorithms for position control. As the EDITH motion control system is designed as an open system, it is, however, easily expandible w.r.t. hardware and software, so that flexibility in the reduction of the sampling time is provided if that is needed (e.g. force control).

9.5.3 Arrangements of the position control loops

To deliver the high torques required to move EDITH-ABT and to have the possibility to avoid backlash by electric backlash removal, some joints of EDITH are supplied with drives which are split into several units. For some of the drive units the control system is using the torque interface of the respective amplifiers, to have the possibility to apply dedicated forces, for other units the respective velocity interfaces will be used According to this the arrangement of the position control loops has to follow table 9.1.

Fig. 9.1: Reference servoloop



ABT					
joint	number of drives	number of motors	number of position control loops	interface	
				torque	velocity
Z1	2	4	1	x	
Z2	1	2	1	x	
Z3	1	2	1	x	
Z4	1	2	1	x	
Z5	1	2	1	x	
Z6	2	2	1	x	
Σ 6	8	14	6		
MU (part)					
joint	number of drives	number of motors	number of position control loops	interface	
				torque	velocity
T01	2	2	1	x	
T02	2	2	1	x	
R01	1	1	1		x
P01	1	1	1		x
P05	1	1	1		x
Σ 5	7	7	5		

Table 9.1 Arrangement of the position control loops Part 1 of 2

DHD					
joint	number of drives	number of motors	number of position control loops	interface	
				torque	velocity
T01	2	2	1	x	
T02	2	2	1	x	
P01	2	2	1		x
R01	1	1	1		x
Y01	1	1	1		x
G01	2	2	1	x	
Σ 6	10	10	6		

AHU					
joint	number of drives	number of motors	number of position control loops	interface	
				torque	velocity
T01	2	2	1	x	
Y01	1	1	1		x
P01	1	2	1		x
R01	1	1	1		x
G01	2	2	1	x	
Σ 5	7	8	1		

Table 9.1 Arrangement of the position control loops Part 2 of 2

9.5.4 Performance

One of the most critical tasks of EDITH is entering the torus-mockup through an entry port. Therefore the following requirements have to be accomplished. The preliminary requirements for the NET ABS werde defined in chapter 2. For EDITH these requirements were scaled down to have more flexibility and reserve in the test facility. Additional requirements for EDITH concerning the performance are:

- The velocity servos must achieve an accuracy of less than 5 % of the commanded joint speed.
- The minimum speed should be less than 0,1 % of maximum joint speed.

9.5.5 Input/Output-Signals

In the following table 9.2 the required input/output-signals for the joint control are summarized.

Remark: The output signals are digital to analog output channels. As electric backlash removal is intended, it is necessary to have different set point currents for the motors of one drive unit. This is a provision for later modifications in the number of control loops devoted for a joint. But first the number of control loops as specified in tab. 9.1 has to be implemented. In cases where backlash removal is not required, and when using the velocity interface only one output-channel must be provided for the amplifiers of the corresponding drive unit.

joint		input					output	
		joint position (resolver) digital signal	joint velocity (resolver) analog signal	motor rotor position (motor-resolver) digital signal	motor rotor velocity (motor resolver) analog signal	force	set point current analog signal	set point velocity analog signal
	Z1	1	1	4	4	2	4	---
A	Z2	1	1	2	2	2	2	---
B	Z3	1	1	2	2	2	2	---
T	Z4	1	1	2	2	2	2	---
	Z5	1	*	---	*	2	2	---
	Z6	1	*	---	*	2	2	---
	T01	1	*	---	*	---	2	---
M	T02	1	*	---	*	---	2	---
U	R01	1	*	---	*	---	---	1
**	P01	1	*	---	*	---	---	1
	P05	1	*	---	*	---	---	1
	T01	1	*	---	*	---	2	---
D	T02	1	*	---	*	1	2	---
H	P01	1	*	---	*	---	---	1
D	R01	1	*	---	*	---	---	1
**	Y01	1	*	---	*	---	---	1
	G01	1	*	---	*	2	2	---
	T01	1	*	---	*	1	2	---
A	P01	1	*	---	*	---	---	1
H	R01	1	*	---	*	---	---	1
U	Y01	1	*	---	*	---	---	1
**	G01	1	*	---	*	2	2	---

*: TBD It is not yet clear whether the joint velocities or the motor rotor velocities will be used. (Quality of the signals etc.)

**: either the MU, DHD, AHU or none is connected to the ABT.

Table 9.2 Required input/output-signals for joint control

To classify the notion of logical output another summary is given in table 9.3 (see also fig. 3.3)

external Interface	t ↓	t ↓	t ↓	t ↓	v ↓	v ↓		v ↓	t ↓	t ↓
servo identification	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
internal interface						t →				
AHU	$T01_1$	$T01_2$	—	—	Y01	$P01_1$	$P01_2$	R01	$G01_1$	$G01_2$
DHD	$T01_1$	$T01_2$	$T02_1$	$T02_2$	R01	$P01_1$	$P01_2$	Y01	$G01_1$	$G01_2$
MU-PU	$T01_1$	$T01_2$	$T02_1$	$T02_2$	R01	P01		P05		

Table 9.3 Possible mappings from joints to control loops and from servos to joint motors

Remark 1:
- t means torque interface
- v means velocity interface
- In the cases where 2 motors are actuating on one joint, the respective motors are identified by the symbolic joint name with a subscript.

Remark 2: Those joints equipped with 2 motors will have mechanically preloaded gears (holds for WU joints only).

Remark 3: For each of the joints T01 and T02 (of any work unit), the respective control loop provides one logical output. Nevertheless the control software has to direct the output to two separate output channels.

10. Documentation

A well structured, coherent documentation will be considered as a part of prime importance.

Thus a complete documentation must be provided especially for

- LLCS hardware
- HBX, HLCS and LLCS software

The documentation of the LLCS hardware must especially contain the final state of the process I/O part.

The software documentation must contain at a minimum:

- RMX configuration
- static description, modules and their call-interdependencies and main data structures
- Task structures and communication relationships
- Protocols and message formats
- algorithms (coordinate transformations)
- complete source code
- general naming convention description

The user manual should clearly separate between the functions for an operator and a system administrator. A complete error list for all possible interactions as well as proposals for according actions is required.

11. References

1 NET Report: Association Technology Program for NET, July 1989

2 Leinemann, K.: Supervisory Control System for NET: Remote Handling Workstation, Motion Controller, Central Utilities.
Unpublished Report of KfK, November 1988

3 Leinemann, K.: IVHU Control System Requirements,Unpublished Report of KfK, September 1989

4 Leinemann, K: NET Remote Workstation. KfK-Primärbericht 17.01.01P25E, April 1990

5 Brown, M.L., Bombi, F.: Functional Specification of the NET Control System. NET N/R/6000/4/A, 26.09.1989

6 Brown, M.L., Bombi, F.: Operational Specification of the NET Control System. NET N/R/6000/5/A, 26.09.1989

7 Ludwig, A.: ROBOT Version 2.1 - Benutzeranleitung. KfK-Primärbericht 17.01.01P17C

8 Kühnapfel, U.: KISMET - Kinematic Simulation, Monitoring, and Off-line Programming Environment for Telerobotics. KfK-Primärbericht 17.01.01P19B, September 1989.

9 Kühnapfel, U.: GBsim - JET Graphical Boom Simulator / Operators Manual. KfK-Primärbericht 17.01.01P02C, August 1987.

10 Köhler, B.: GMS - a high-precision Geometry Measurement System for large fusion reactor components. IAEA Technical Committee Meeting on Robotics and Remote Maintenance Concepts for Fusion Machines, Karlsruhe, 22.-24.2. 1988

11 Breitwieser, H. et al.: Zusammenfassender Bericht über die Arbeiten zur Kamera- und Trägersystemsteuerung CATSYS. KfK-Primärbericht 17.01.01P02D, Sept. 1987.

12 Benner, J., Leinemann, K.: Architecture of a Telemanipulation System with Combined Sensory and Operator Control. RoViSeC-7 (1988) S.259-270

13 Breitwieser, H.: A control system supporting different modes of telemanipulator operation for in-vessel handling. IAEA Technical Committee Meeting on Robotics and Remote Maintenance Concepts for Fusion Machines, Karlsruhe, 22-24.2.1988

14 ISO7DIS 9506 Manufacturing Message Specification, 1988

15 IRDATA - Schnittstelle zwischen Programmierung und Robotersteuerung. DIN 66313, Teil 1, 1989

16 Galbiati, L.: ANNEX B2 Technical Specification for the Supply fo TARM Control System, 27.3.1987, LG|pn|S031

17 Galbiati, L.; Benali, G.: TARM Control System - Handbox software description, LG|U|024

18 Maisonnier, D.: NET/ITER In-Vessel Transporters Requirements Definition for its Conceptual and Preliminary Design. Issue: DRAFT, 10.5.1989; N2/P/3240/1/A, 6.4.1989 (me)

19 Weber, W.: Regelung von Manipulator- und Roboterarmen mit reduzierten inversen Modellen. Fortschritt Berichte VDI Reihe 8, Nr. 183, 1989

20 Weber, W., Süss, U.: Untersuchung und Realisierung einer adaptiven Gelenkregelung nach dem Referenzmodellkonzept. VDI Berichte Nr. 598, 1986

List of abbreviations

Chapter:

Chapter		
1	TARM	telescopic arm; remote handling equipment of JET
	EDITH	experimental device for in-torus handling
	ABS	articulated boom system (= superset of EDITH)
	WU	work unit (part of EDITH)
	ABT	articulated boom transporter (joints Z1, ... , Z6)
	MU	manipulator unit (special WU)
	AHU	antenna handling unit (special WU)
	DHD	divertor module handling device (special WU)
	ASB	ASB, Gesellschaft für Positionier- u. Antriebssysteme mbH, 7525 Bad Schönborn, Germany
	FSR	flexibler Servo Regler
	AC S	alternating current sinus type
3	ABT-main-joint group Z1, ... , Z4 (fig. 2.2)	
	DC	direct current (this is no contradiction to AC amplifier; the terminology of the suppliers is not consistent)
4	NET	next european torus
	RH	remote handling
	NRWS	net remote handling work station
	RHWS	remote handling work station
	Multibus II	32-bit bus architecture, international standard, trademark of Intel Inc.
	iRMX	Intel real time operating system, trademark of Intel Inc.
	CPU	central processing unit
	TCP/IP	protocol architecture and de facto standard originating from DARPA, suited for local area networks as well as for wide area networks
	ERWS	EDITH remote workstation, main man-machine-interface at the top level of the complete EDITH control system hierarchy
	HLCS	high level control system; JET terminology
	HBX	hand box; JET-terminology
	LLCS	low level control system; JET-terminology
	DEC	Digital Equipment Corp., USA
	VAX	famous computer series of DEC
	AT	advanced technology; IBM's personal computer de facto international standard

	IEEE 802.3	international standard for base band communication (Ethernet)
	80386	powerful microprocessor chip from Intel (in general one assumes that a 80387 numeric coprocessor is also present)
	KfK	Kernforschungszentrum Karlsruhe, Nuclear Research Center Karlsruhe
5	VMS	name of DEC's most common operating system for VAX series
	SCS	supervisory control system, upper control system hierarchy levels above motion control system
	OSI/ISO-8073	international standard from ISO for the transport protocols and services. The transport level is an intermediate level of the open systems (OSI) communication architecture
	MB	Mega Byte
	RS 232 C	standard for serial communication equipment (V 24)
	Q-Bus	standard Bus architecture for DEC computers (μ-series)
	INTERLAN	name of manufacturer of Ethernet communication boards and related equipment
	MVMSNET	Micro-Vax-VMS-Network compatible with the OPEN-NET protocols
	VOTS	Vax OSI Transport Service, DEC's implementation of the transport level services
	iNA 960	Intel's Network architecture, comprises level 1 ... 4 of the OSI 7-level-communication architecture
	MS-DOS	Micro Soft Inc. - Disk Operating System; de facto industry standard for AT PCs.
	Lap Top	Leight weight, slim size portable PC type
6	CSM	central service modul, needed for any Multibus-II system
	SCSI	small computer systems interface, international standard for interfacing storage and other peripheral equipment
	LAN	local area network (eg. Ethernet)
	iSBX	Intel's system extension bus, usually SBC boards can carry via iSBX small piggy back boards
	KB	kilo Byte
7	AMD	Analog Devices Inc., USA
	2580	a famous chip from AMD for resolver-signal to digital conversion
	AMP	AMP Inc., USA

EDITH-ABT-Group
either joints, amplifiers or motors for Z1, ... , Z6 (cf. fig. 2.2)

WU-Group either joints, amplifiers or motors for WUs

EDITH-ABT-Main-Amplifier Sub Group
amplifiers for the motors for Z1, ... , Z4

T.B.D to be defined

RMA name of a converter board of Gerwah Inc., Industriering 18-20, 8751 Großwallstadt, Germany

GAG Gerwah Meßgetriebe

8 C name of a programming language

DOS short form for MS-DOS

ISRA ISRA Systemtechnik GmbH, Darmstadt, Germany

POR point of referency (JET terminology) ≙ MCP

CCS control coordinate system, basis where directions for commanding motions will be referenced to

MU-PU manipulator positioning unit, part of MU to be controlled by the motion control system

9 BCS base coordinate system (= K0 in fig. 2.2)

MRF manipulator reference frame, defines point plus direction of a coordinate system attached to the link which is moved by Z4

MCP manipulator control point, same as POR

Synonyms:

This report uses terms introduced in /7/. As this text is based on two ealier reports for EDITH Motion Control System Requirements Definitions the following table has been included:

ABT	TU
DHD	DHU
ABS	IVHU

Appendix A. COORDINATE SYSTEMS

To control the manipulator motion problem suited some coordinate systems are defined, which will be described in the following chapters and in Figure A.1.

A.1 Base coordinate system

The base coordinate system (BCS) serves as general reference.

All the geometry data references the **NET-world-coordinate-system (NWCS).** In this paper we assume (with reference to drawing IT-OUT-07-008), that

- the base point of the NWCS lies in the torus midplane on the vertical torus axis,
- the positive x-axis points from south to north in the torus midplane
- the positive x-axis points upwards
- the positive z-axis is defined such that x, y and z form a cartesian coordinate system (right-hand rule)

A special auxiliary base coordinate subsystem is the **Vessel-coordinate-system (VCS)**. This is a system of cylindrical coordinates with the r-∅-plane coinciding with the x-y-plane of the NWCS. The origin and the z-axis are the same as for the NWCS. The azimuthal angle ∅ = 0 corresponds to the x-axis of the NWCS.

A.2 Joint coordinate system

Each joint of the kinematic chain has its own coordinate system defined according to the DH (Denavit-Hartenberg) conventions.

A.3 Control coordinate system

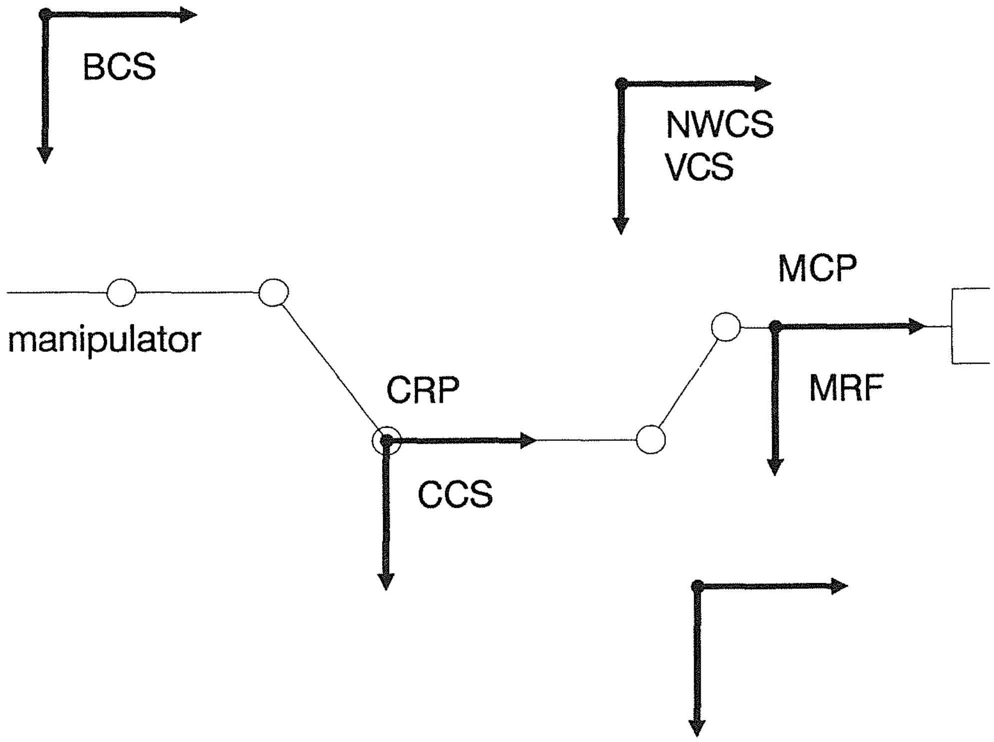
The control coordinate system (CCS) is a special cartesian coordinate system to describe motions. This coordinate system may be attached to the manipulator or to the environment.

A.4 Manipulator reference frame

The manipulator reference frame (MRF) is a coordinate system representing the manipulator during motions. This frame corresponds to the TCP in robotics.

A.5 Target frame

The target frame (TRF) describes the target of a motion. After a motion the MFR lies on the TRF.



BCS: base coordinate system
NWCS: NET world coordinate system
VCS: vessel coordinate system
CCS: control coordinate system
MRF: manipulator reference frame (tool reference frame)
MCP: manipulator control point (TCP in robotics)
TRF: target reference frame

Figure A.1 **Coordinate systems description.** In a manipulation task the MRF has to be moved to the TRF. The CCS may be attached to the manipulator or the environment. The MRF is moved in the CCS-. A typical special case is given when CCS and MFR coincide.

Appendix B. MOTION DESCRIPTION

For motion description of **redundant kinematic systems** two concepts are defined:

PATH.

A path is a sequence of manipulator reference frames together with a set of (redundant) joints driven according to predefined algorithms while the remaining joints are driven such as to perform the desired path. A path may be translated, that means may be repeated at another place. The element of a path is called a path-position which includes an orientation. While repetiting a path, the operator may override the motion by a correcting input for example via a joystick. This means correcting the motion of the MRF.

CONFIGURATION SEQUENCE

A **C__sequence** (configuration sequence) describes the motion of all joints of a manipulator. A C__sequence is not movable in space, that means the motion pattern described by a C__sequence may not be repeated at another position, for example 1 m to the right. The element of a configuration sequence is called a **configuration** (a set of all joint parameters of a manipulator).

Appendix C. RESOLVED MOTION

The resolved motion problem for redundant kinematics (ABS) shall be solved pragmatically by removing redundancy manually. That means, the operator has to select joints for motions in world coordinates, such that the required transformations are nonredundant.

Resolved motion describes the motion of the MCP in the CCS (Figure 6). MCP and CCS have to be defined by the operator. The MCP usually will be attached to a joint axis. Two control modes are provided:

1. Control of two down-chain joints and CRP joint
2. Control of two down-chain joints, two up-chain joints, and the CRP joint. In this case the up-chain structure is fixed in space. This mode is a special case of reconfiguration mode. The orientation of the MRF is defined separately.

   Controlled joints need not be adjacent.

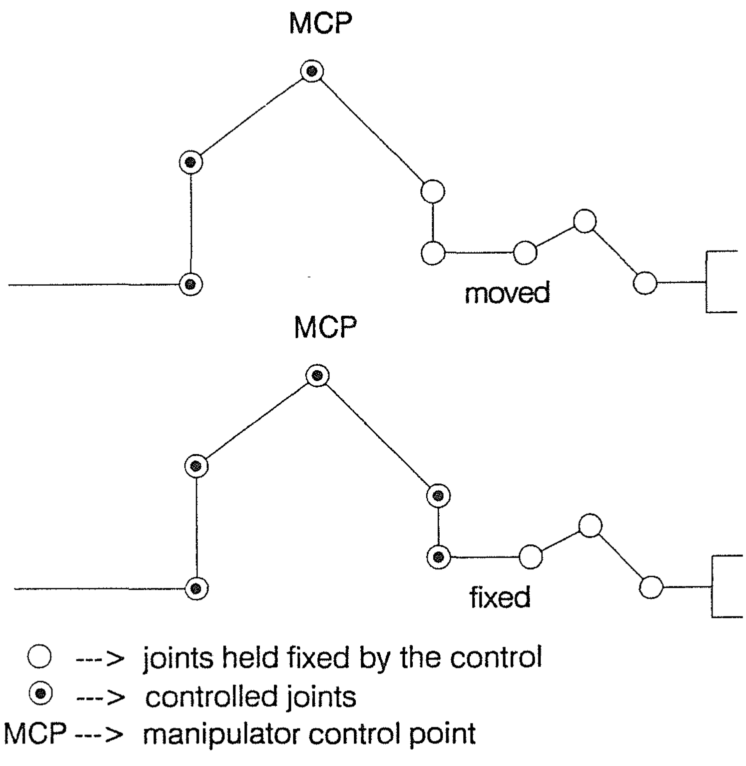


Figure C.1 Resolved motion control

Reconfiguration

Reconfiguration is a very helpful mode in maneuvering in a narrow environment. In this case three joints are controlled by the system, one joint is controlled by the operator directly. The controlled joints need not be adjacent (Figure C.2). From the operator's point of view this is a special type of joint motion control.

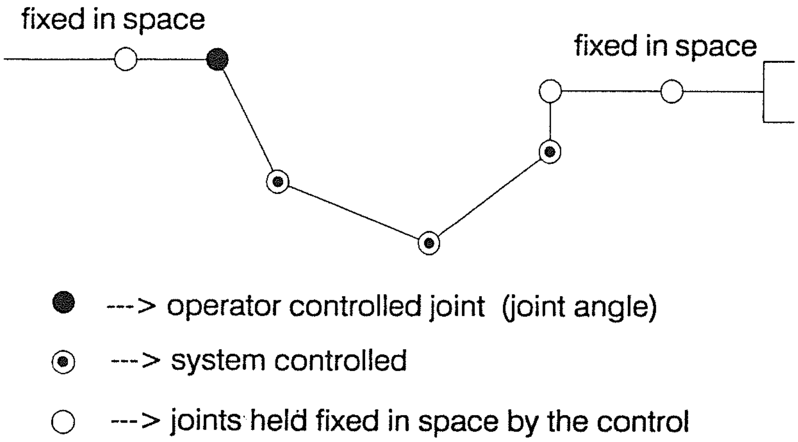


Figure C.2. Reconfiguration mode

Appendix D. GLOSSARY

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.

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 nonrealtime environment Ethernet (IEEE 802.3) is mostly used; in the realtime 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 recommended.

D

Dead time. Time lack due to signal (command) transport through the system, including the closed loop control.

E

ERWS. See NRWS

H

Hardware. As hardware base for the development of the control system MULTIBUS II boards should be used. Possible solutions for the RH-area controller, if not implemented on MULTIBUS II boards, are general purpose mini computers as VAX or workstations.

M

Motion data format. Such a data format describes robot tasks in form of robot programs. A DIN-standard which should be used for up/downloading programs between the NRWS and RH-area control system (e.g. the ABS control system) is IRDATA (Industrial Robot Data). Further standardization activities are underway.

N

NET remote 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 (operating interface) and a various high level (task oriented) support tools for the operator. The NRWS represents the "guidance system" of the RH control system. The ERWS (EDITH Remote Workstation) is a prototype of the NRWS.

NET control system (NCS). The overall control system of the NET plant. The RH control system is a subsystem of the NET control system.

O

Operating system. The recommended standard for real-time purposes is iRMX, for RH-area control VMS or UNIX may be used.

Operating interface. The operating interface of a control system is that part of the man-machine interface dedicated to basic equipment control. The operating interface should be realized as an independent software module, providing the basic features needed to work with the equipment.

Programming language. The programming language is the language used for implementing the control system modules.

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 controll 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. ABS, BHU) and its supporting devices. A RH-area has a separate communication channel. Manufacturing cells in manufacturing plants are similiar units.

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.

T

Time response. The distance at which a tangent drawn to the response curve at the point of maximum slope intersects the horizontal time axis.

U

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

- easy to use interactive behaviour of interfaces,
- a distinctive 3D apperarance of the windows.

The provided tools are:

- application program interface,
- common user interface for all NRWS modules and all panel displays,
- a single, stable widely available applications programming interface
- user interface toolkit,
- presentation description language,
- window manager,
- style guide.

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 differnt 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 accesed 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.