



**FUSION
FOR
ENERGY**

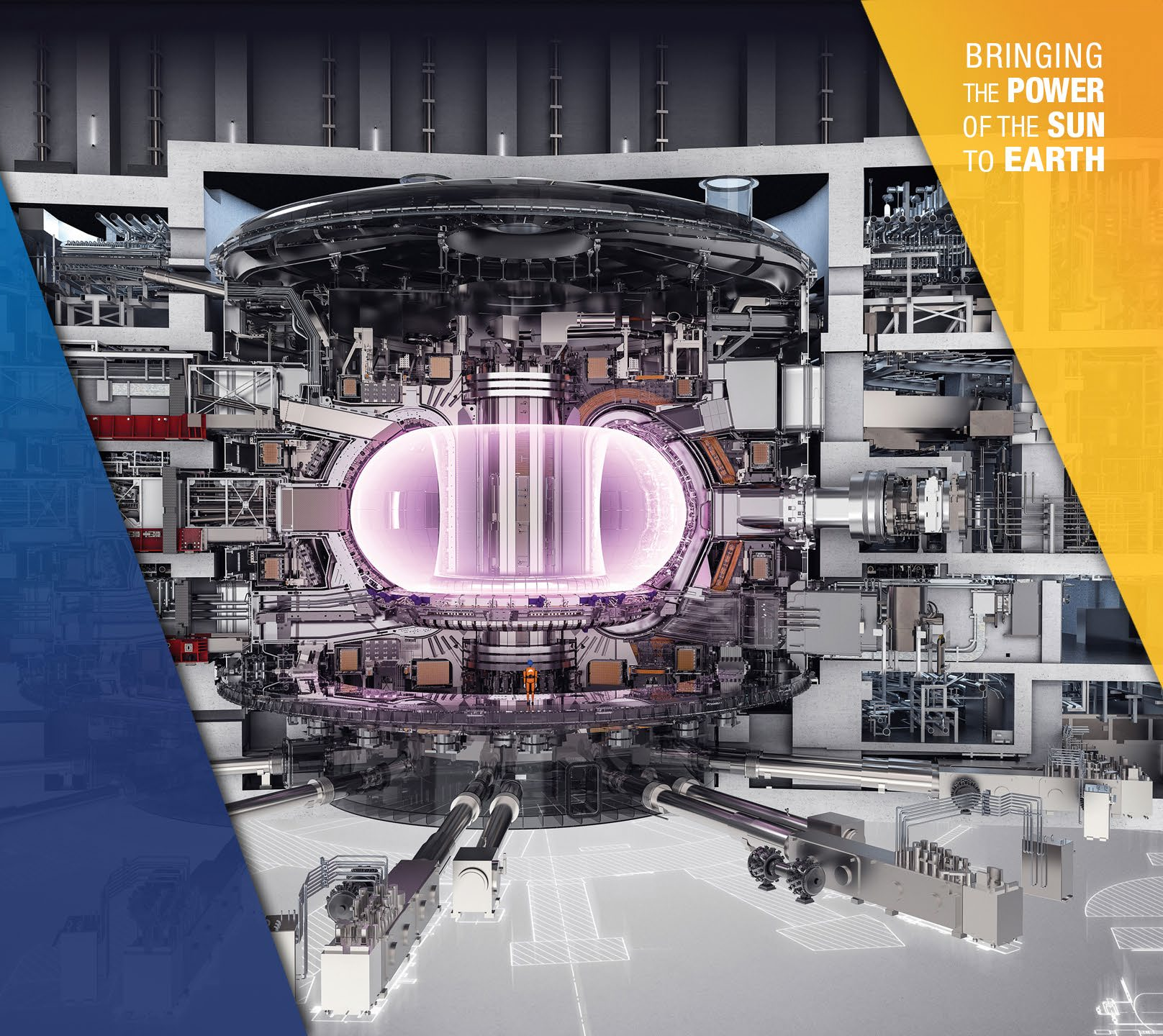
BRINGING
THE **POWER**
OF THE **SUN**
TO **EARTH**

DAT Control System

Emilio Ruiz

Remote Handling Program
Manager

04/11/2024



DAT Control System Distribution



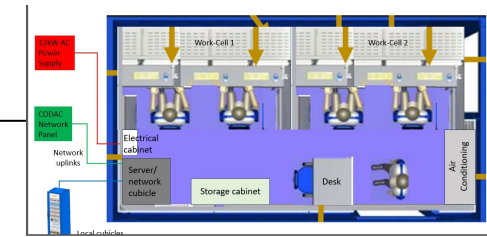
Cubicles on B1 in gallery corners for CMM and in adjacent port cells for CTMs



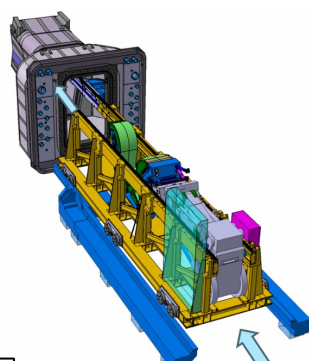
Networks



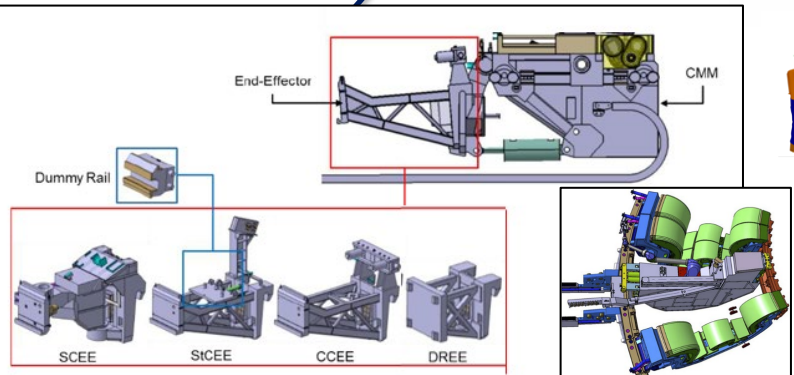
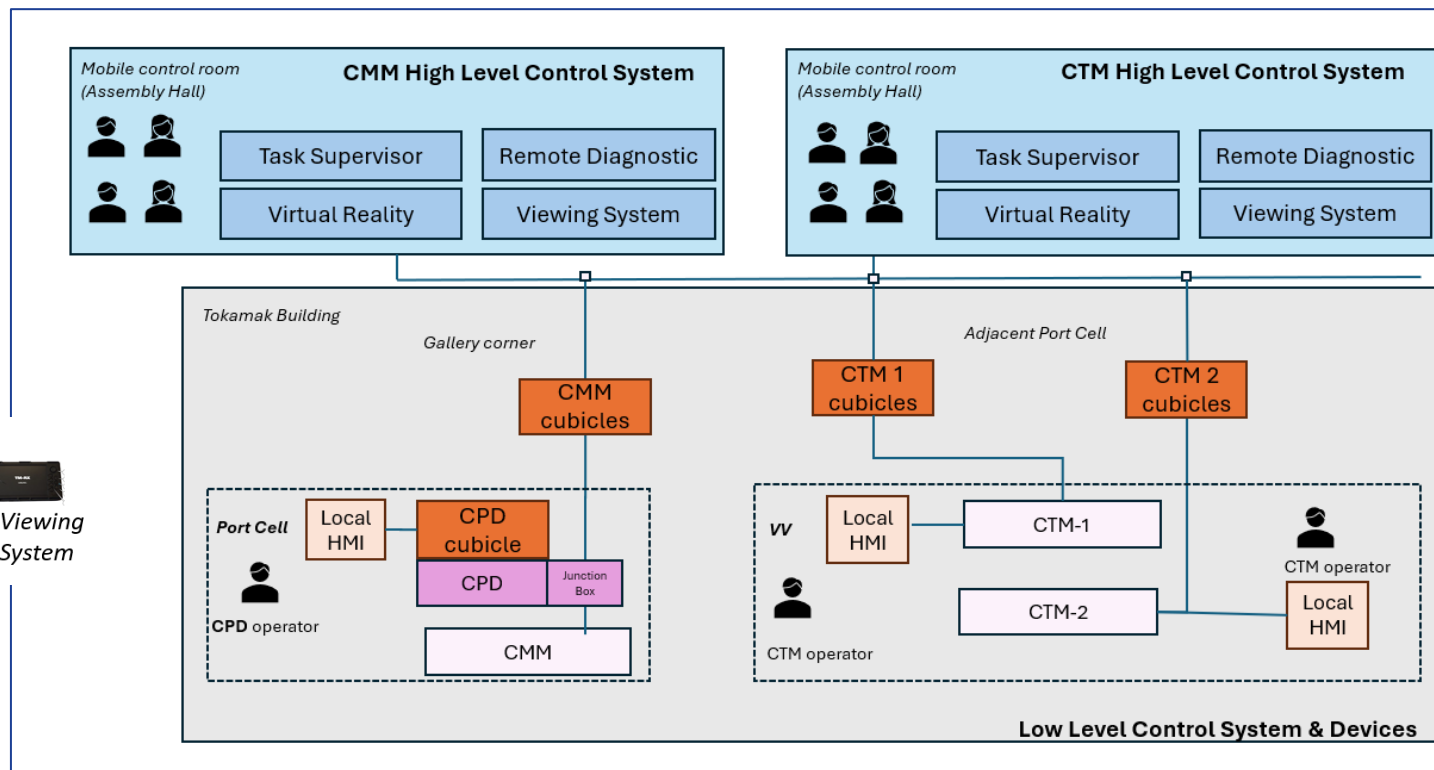
Mobile Control Room in Assembly Hall



Port-cell operations

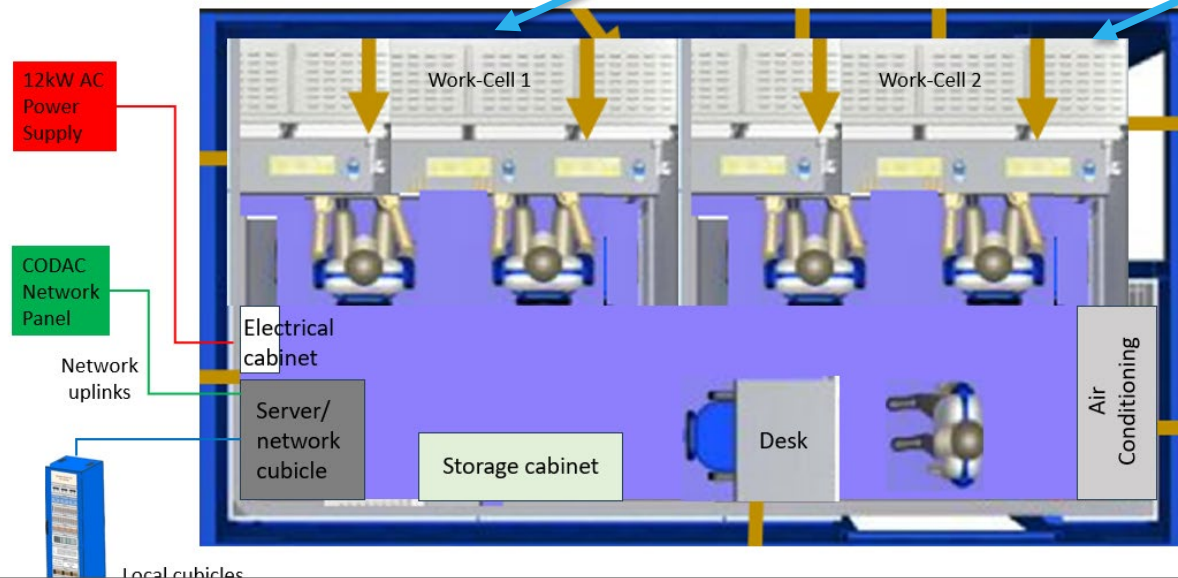
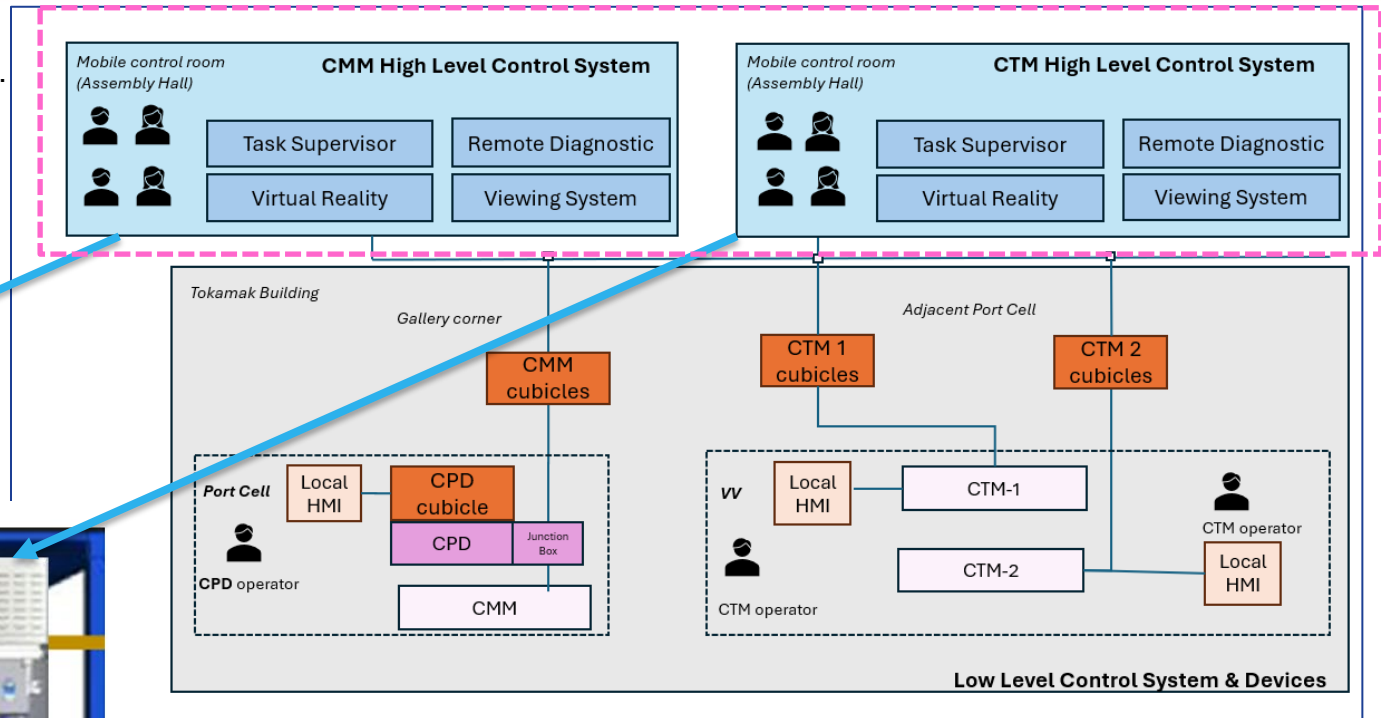
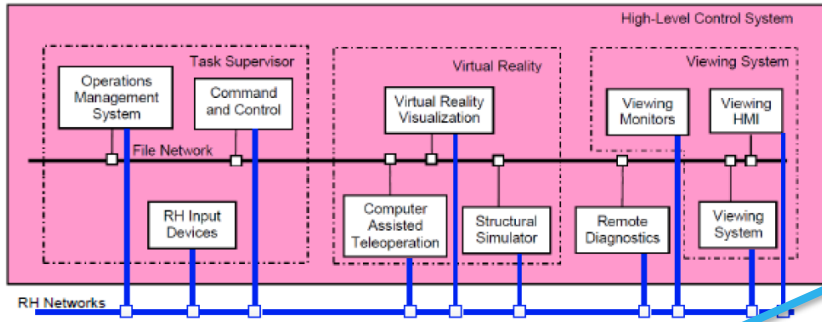


Cabling



DAT Control Room and High-Level Control System

The High-Level Control System (HLCS) implements all the operator interfaces and components for the planning and execution of RH operations.

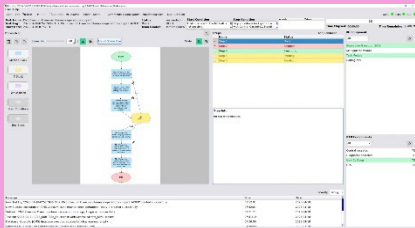


HLCS will be implemented in a mobile control room. It is a container including the work cells for the operators to control the DAT CTMs and CMM. It is easy to transport and can be used for FAT, SAT and operations.

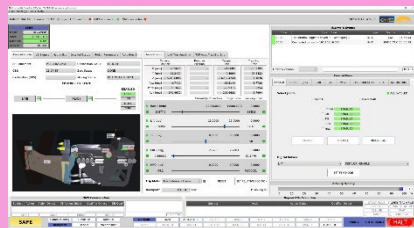
High Level Control System - Operators Interfaces

HIGH LEVEL CONTROL SYSTEM

Operation Management System (OMS) to manage step by step operations sequences of RH tasks. GUIs for building, executing and analyzing RH tasks.



Command and Control (C&C): the primary operator GUI to remotely control and monitor RH devices through RH networks; interfaced to a Joystick for manually driven motion.

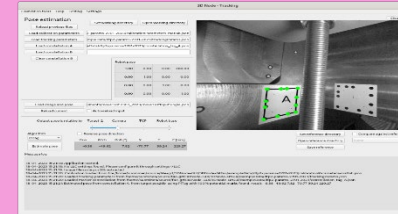


Virtual Reality (VR): to complement the Viewing System, to simulate **structural deformations**, to enable the anticipated detection of collision, to assist **Teleoperation**



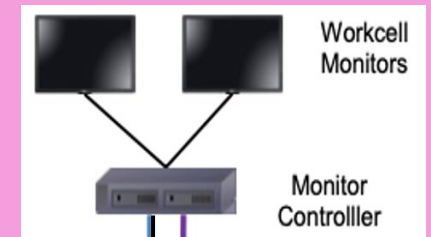
VIRTUAL REALITY SYSTEM

3DNode Machine Vision: to assist RH operations and Tele-operation.



RH OPERATIONS ASSISTANCE TOOLS

Viewing System (VS) for displaying camera views on the monitor displays of the RH workcell.



File Network

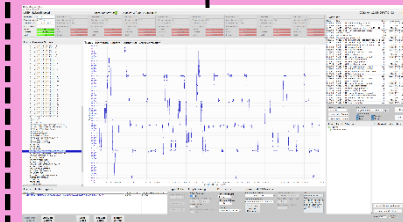
Emergency Stop button



Joystick

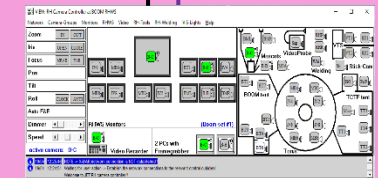


TASK SUPERVISOR



REMOTE DIAGNOSTICS

Remote Diagnostic System (RDS) enabling the monitoring of the equipment health status to detect and diagnose equipment degradation, before failure occur.



VIEWING SYSTEM

RH Control and Diagnostic Network

RH Real-Time Network

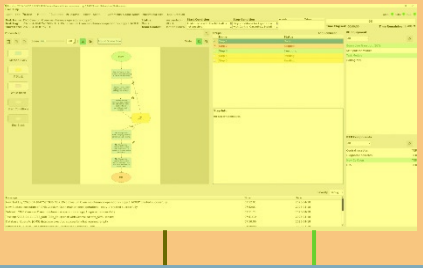
RH Audio-Video Network

RH Estop Network

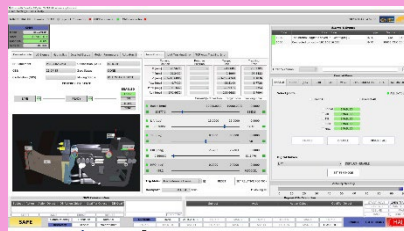
High Level Control System Outline

HIGH LEVEL CONTROL SYSTEM

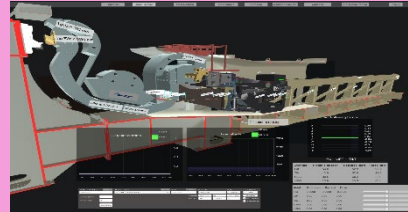
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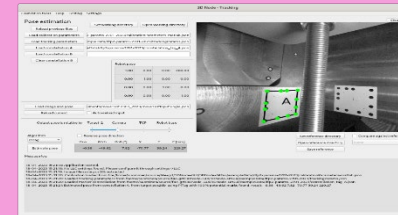


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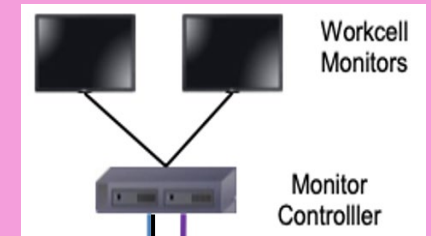
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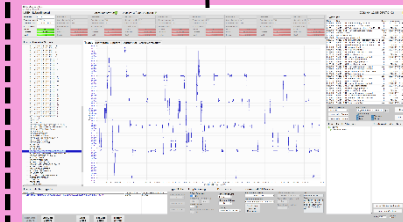
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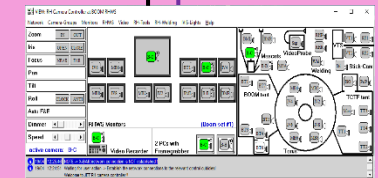


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Remote Diagnostic System (RDS) enabling the monitoring of the equipment health status to detect degradation, anticipate and diagnose failures.

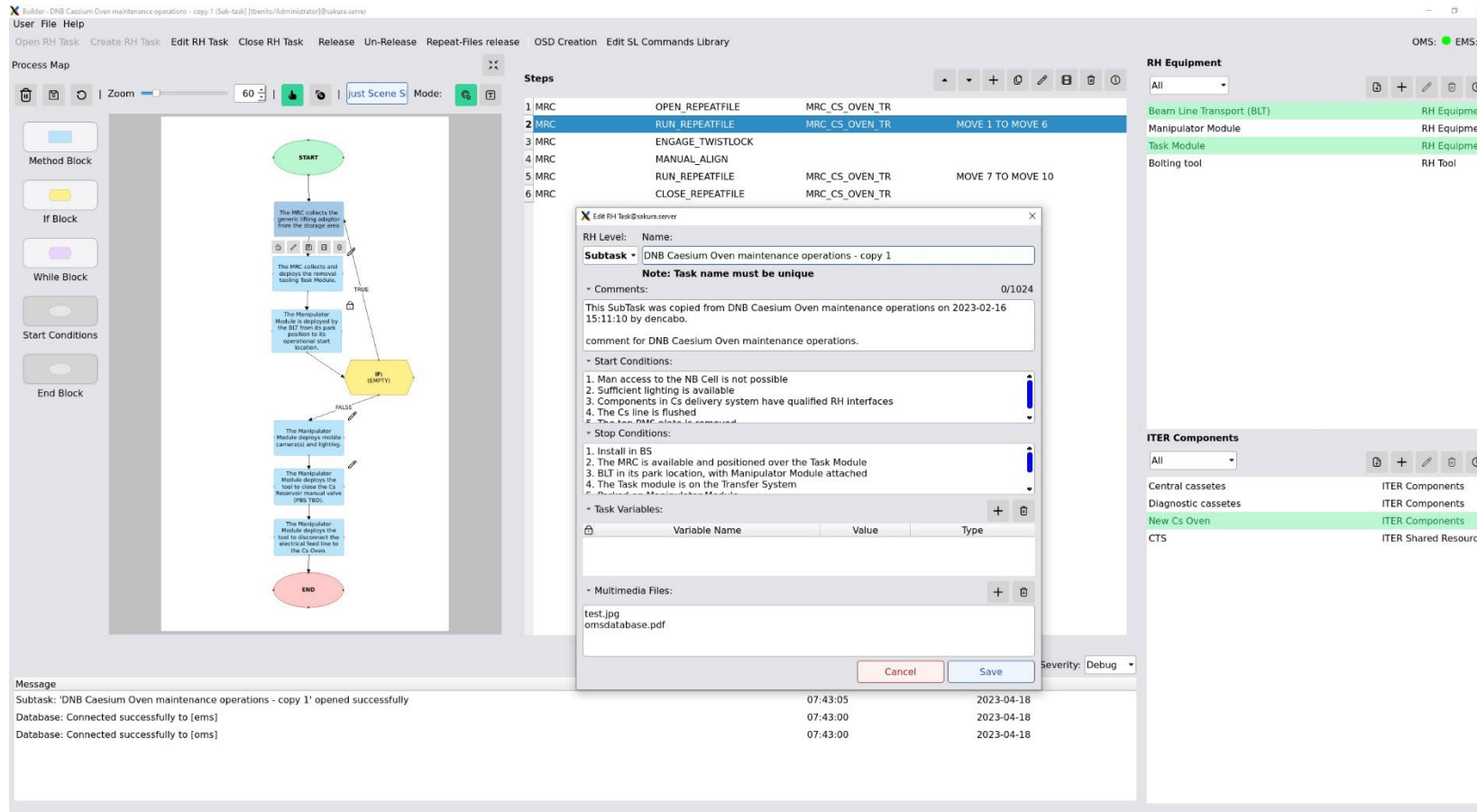


File Network

RH Control and Diagnostic Network

RH Audio-Video Network

RH Estop Network



The screenshot displays the OMS software interface. On the left, a 'Process Map' shows a flowchart starting with 'START', followed by several task blocks, an 'IF (EMPTY)' decision block, and ending with 'END'. The main area shows a 'Steps' list:

Step	Task Name	Equipment	Notes
1	MRC OPEN_REPEATFILE	MRC_CS_OVEN_TR	
2	MRC RUN_REPEATFILE	MRC_CS_OVEN_TR	MOVE 1 TO MOVE 6
3	MRC ENGAGE_TWISTLOCK		
4	MRC MANUAL_ALIGN		
5	MRC RUN_REPEATFILE	MRC_CS_OVEN_TR	MOVE 7 TO MOVE 10
6	MRC CLOSE_REPEATFILE	MRC_CS_OVEN_TR	

An 'Edit RH Task' window is open, showing details for the subtask 'DNB Caesium Oven maintenance operations - copy 1'. It includes a 'Note: Task name must be unique', a comment, start and stop conditions, and a table for task variables.

Variable Name	Value	Type

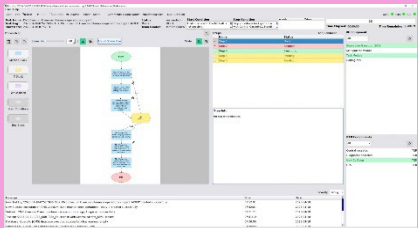
At the bottom, a 'Message' pane shows: 'Subtask: 'DNB Caesium Oven maintenance operations - copy 1' opened successfully' at 07:43:05 on 2023-04-18.

- ❑ The OMS has 3 GUIs to plan, execute and analyze RH Tasks
- ❑ Developed on Qt[®] using C++ language
- ❑ implementing a SIL-1 equivalent development process
- ❑ OMS Planning GUI capability:
 - Off-line programming of RH tasks by editing programs in RH structured language, verifying the program on VR.
- ❑ OMS Execution GUI capability:
 - VR environment set-up from OMS
 - RH task program load from the RH database
 - verification of equipment and tools availability
 - step-by-step execution, sending instructions to C&C
 - Recording of execution status and observations
 - Reporting to the RH Supervisory Control System
- ❑ OMS Operations Analysis GUI:
 - Provides tools to generate reports on maintenance activities or anomalies, and to analyze the efficiency of operations for future improvement
- ❑ Provided by F4E as an executable free-issue item ready to use for DAT

High Level Control System Outline

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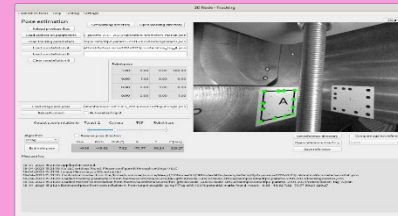


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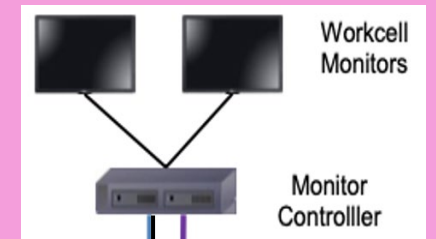
VIRTUAL REALITY SYSTEM

3DNode Machine Vision: to assist RH operations and Tele-operation.



RH OPERATIONS ASSISTANCE TOOLS

Viewing System (VS) for displaying camera views on the monitor displays of the RH workcell.



VIEWING SYSTEM

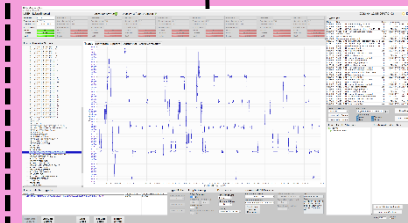
Emergency Stop button



Joystick

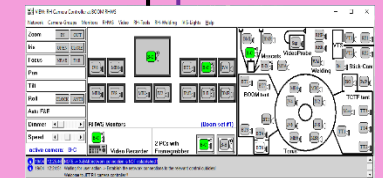


TASK SUPERVISOR



REMOTE DIAGNOSTICS

Remote Diagnostic System (RDS) enabling the monitoring of the equipment health status to detect degradation, anticipate and diagnose failures.



File Network

RH Control and Diagnostic Network

RH Audio-Video Network

RH Estop Network

Command and Control (C&C)



The screenshot displays the Command and Control (C&C) interface for a robotic system. Key components include:

- Mode and Status:** Mode is set to RECOVERY, State is JOINT HOLD, Connect is ALIVE, and Session is CONTROL.
- Controller State:** Shows a sequence of states: SAFE → READY → JOG → MOVE → ZERO.
- Positioning Data:**

Current Position	Relative Position	Target Pose	Tracking Error
X [mm]: 28.5621	--	-21.6685	-50.2305
Y [mm]: -99.3432	--	-0.4999	98.8433
Z [mm]: -16210.6096	--	-16209.4260	1.1836
Yaw [deg]: -9.7420	--	-11.5149	-1.7728
Pitch [deg]: -80.1669	--	-79.9315	0.2354
Roll [deg]: -170.4677	--	-168.6683	1.7994
- Radial Joint Control:** Sliders for Radial [mm], Lift [deg], Tilt [deg], CRO [deg], and HRO [deg] with corresponding tracking error values.
- Alarms & Events:** A table listing system events:

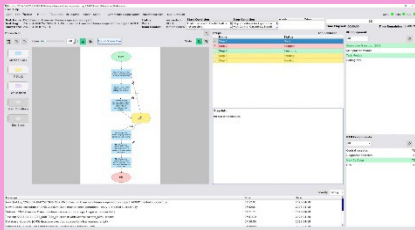
Code	Description	Type	Source	Time
1000	The internal logger is saved in: ../config/log2/	INFO	C&C	14:55:54
1006	Connected to host = 192.168.16.118	INFO	RHDB_C&C	14:55:53
- Control Pane:** Includes buttons for ENABLE, ZERO, JOG, RDB, I/O, MOVE, RHPC EMULATOR, HPU, and ACTUATORS. A 'Select Joints' section shows Radial, Lift, Tilt, CRO, and HRO all as ENABLED.
- Digital Valves:** A dropdown menu for LIFT is set to DEFAULT - ENABLE, with a SET FSM MODE button.
- Velocity Scaling:** A slider ranging from 0 to 100%.
- Repeat-File Execution:** A progress bar and control buttons (START MOVE, SUSPEND, RESUME, HALT, OPEN TEACH FILE, MANUAL ALIGN, WAIT, TERMINATE).
- OMS Collaboration:** A table for tracking actions and objects.
- Bottom Panel:** Safety status (SAFE) and a row of task buttons (Commissioning, Recovery, Hands on, Rescue, Maintenance, GENERIC, MOVE, ACTUATORS, TASK 2-16, TEACH FILE, ENABLE, GOTO READY, HALT).

- ❑ The C&C GUI can control all DAT devices
- ❑ C&C GUI layout with areas for RH devices general statuses, data monitoring, commands controls, alarms monitoring, teach and repeat of sequences, and interface to OMS
- ❑ C&C manages a Joystick for JOG commands, activate moves, trim velocity scale
- ❑ Developed on Qt[®] using C++ language, following a SIL-1 equivalent development process
- ❑ C&C for DAT-CMM developed at DTP2 and C&C for DAT-CTM pre-configured by F4E
- ❑ C&C version for teach-pendant also will be available
- ❑ C&Cs provided as a free-issue items to the Supplier with source code, documentation and training
- ❑ C&C might require minor configuration and functional updates

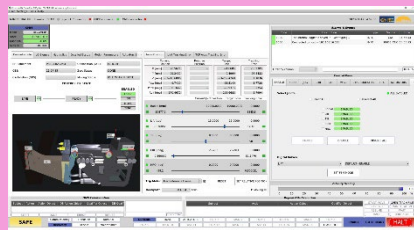
High Level Control System Outline

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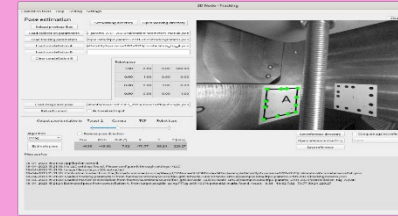


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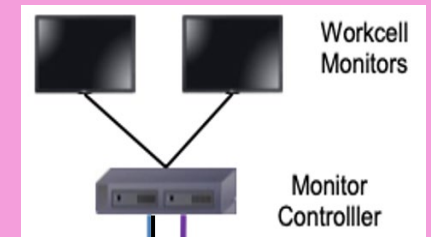
VIRTUAL REALITY SYSTEM

3DNode Machine Vision: to assist RH operations and Tele-operation.



RH OPERATIONS ASSISTANCE TOOLS

Viewing System (VS) for displaying camera views on the monitor displays of the RH workcell.



Workcell Monitors
Monitor Controller

File Network

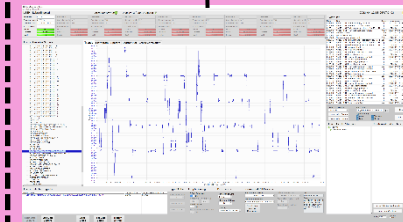
Emergency Stop button



Joystick

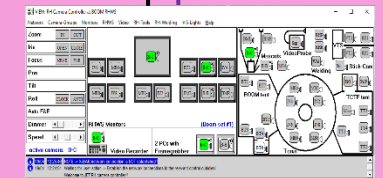


TASK SUPERVISOR



REMOTE DIAGNOSTICS

Remote Diagnostic System (RDS) enabling the monitoring of the equipment health status to detect degradation, anticipate and diagnose failures.

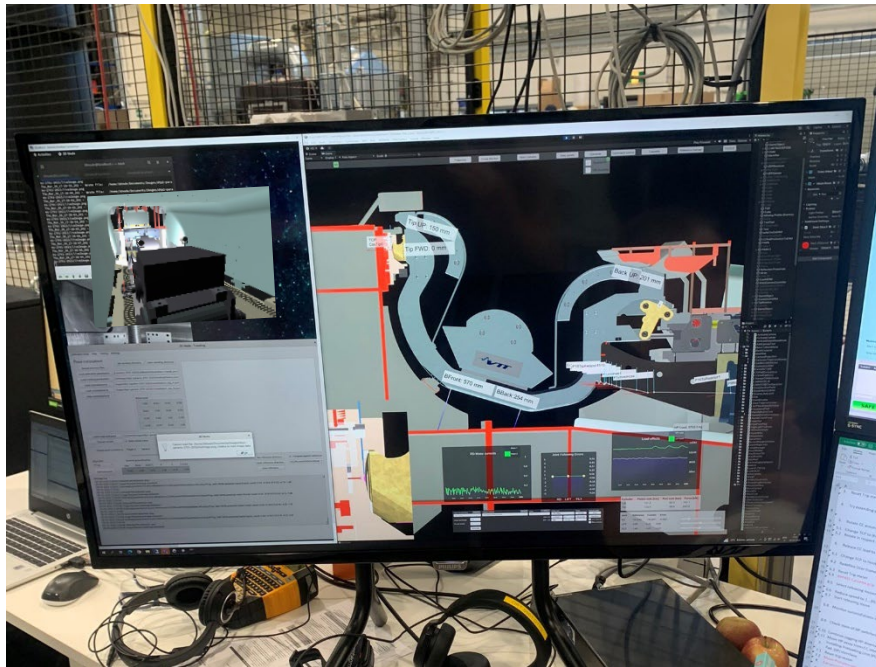


VIEWING SYSTEM

RH Control and Diagnostic Network

RH Audio-Video Network

RH Estop Network



❑ VR – main capabilities:

- VR implemented by VR4Robots from TreeC
- Accurate 3D Modelling of RH devices and the environment:
 - Tools for importing models from CAD
 - Calibration and adjustment of the VR environment to match the real world
- Real-time monitoring RH devices in the VR environment by updating VR models using data read from controllers at up to 20Hz.
- Detection of collisions of between VR models of RH devices and the environment, with the capability to inform the operator and to stop motion (implemented on GENROBOT)
- Augmented visualization of RH devices operations through multi-views including equipment and process information as: equipment and connection status, sensory data (using visual indicators or graphs), deviation from nominal trajectory, actual control frame, target point, etc.

❑ VR - Structural Simulation capabilities:

- Modelling of dynamics effects to visualize equipment deformations under load (e.g. Divertor Cassette deformation when compressed, CMM deformation when loaded, etc.)

❑ VR - Computer Aided Teleoperation:

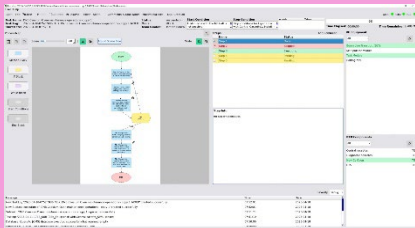
- Automatic adjustment of models using 3DNode machine vision information
- Limitation of workspace or of motion path when moving

❑ VR models and VR4Robots configuration prepared by F4E and transferred to the Supplier who is responsible for VR4Robots installation and license purchase

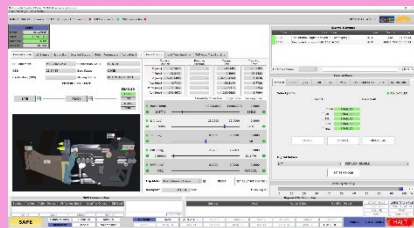
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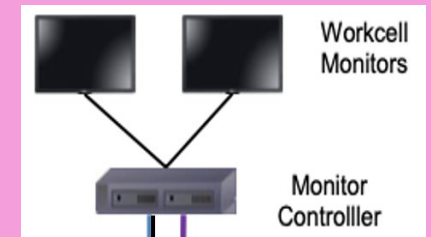
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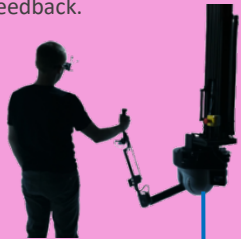
RH OPERATIONS ASSISTANCE TOOLS

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File Network

Master Haptic Arm to tele-operate the MAM slave arm with force feedback.



Emergency Stop button

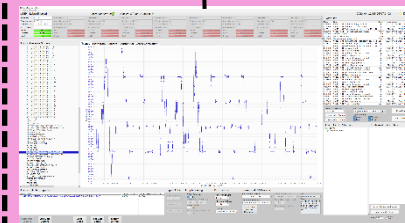


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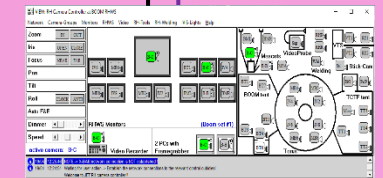


TASK SUPERVISOR

Remote Diagnostic System (RDS) enabling the monitoring of the equipment health status to detect degradation, anticipate and diagnose failures.



REMOTE DIAGNOSTICS



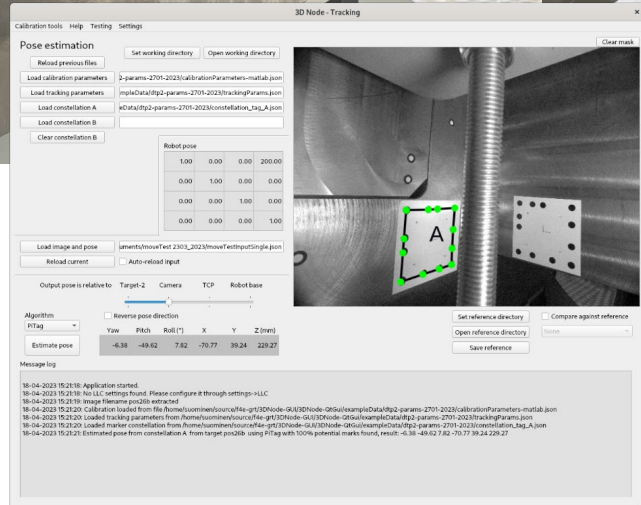
VIEWING SYSTEM

RH Control and Diagnostic Network

RH Real-Time Network

RH Audio-Video Network

RH Estop Network



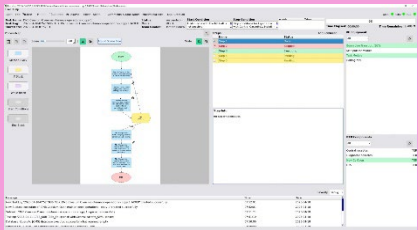
3DNode – main capabilities:

- Provides Cross-hair marks detection for manual alignment
- provides accurate (<+/-1.5mm) and reliable pose estimates of constellation of markers and PI tags, can be used in CCOR alignment
- **Available as a Free-issue item to the supplier**

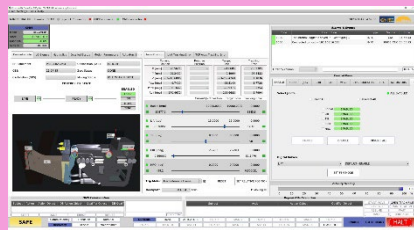
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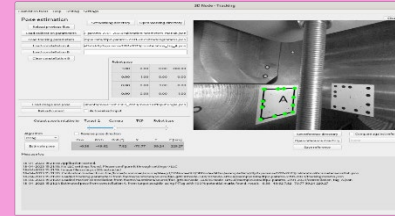


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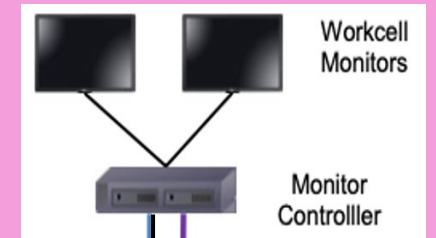
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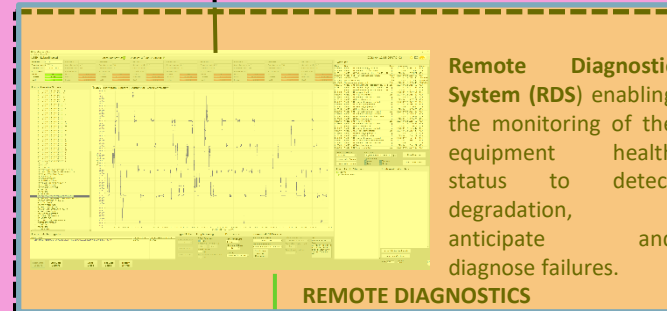
Emergency Stop button



Joystick



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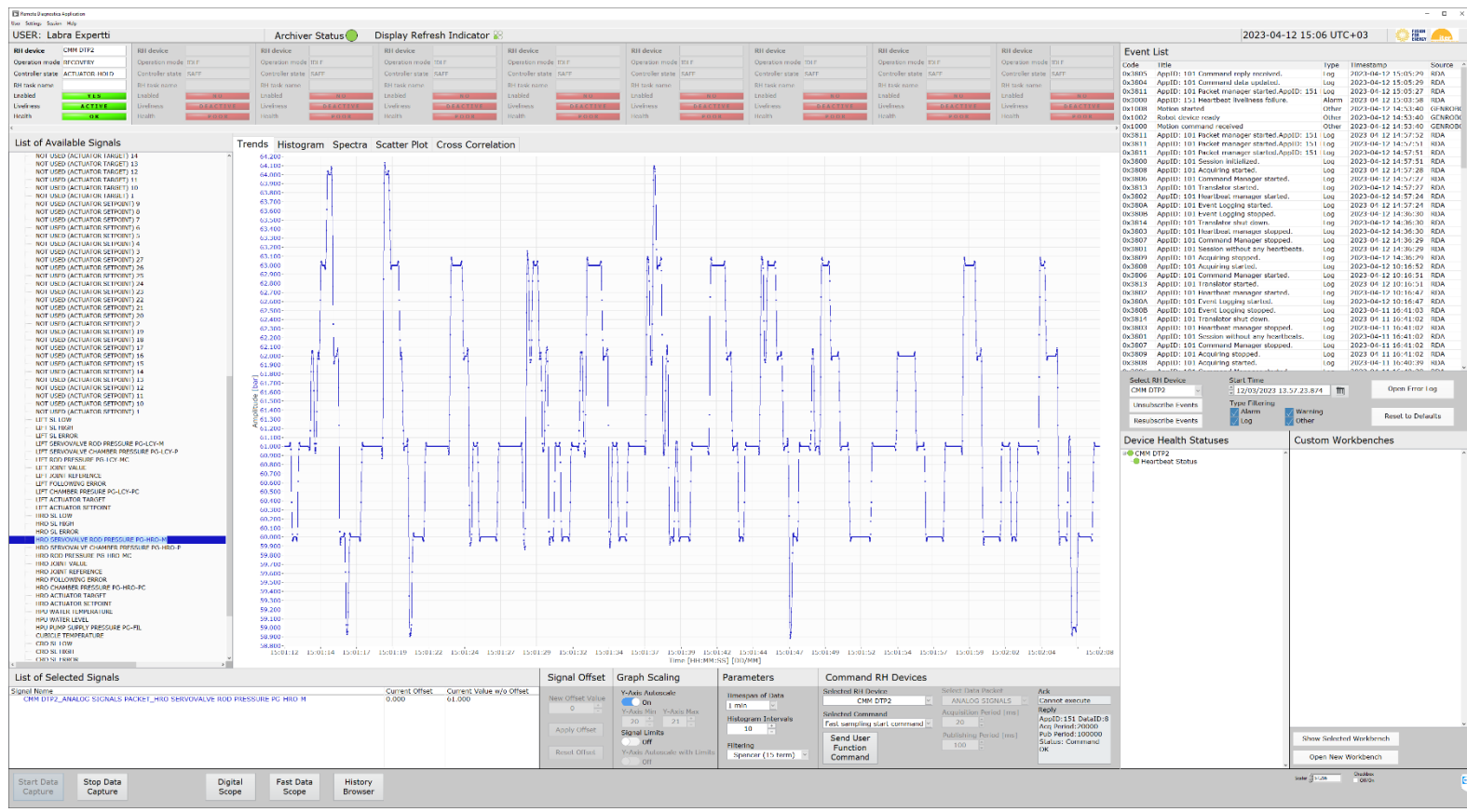
RH Control and Diagnostic Network

RH Audio-Video Network

RH Estop Network

Remote Diagnostic System(RDS)

- Monitor equipment health state using data and events published by RH equipment controllers over the RH Control and Diagnostic Network (RHCDN)
- Detect equipment degradation before failure event by monitoring deviations with respect to nominal condition.
- Warn and inform the operator in case of anomaly by publication of warnings
- Provide tools to implement condition monitoring algorithms applied to incoming
- Provide tools to implement diagnostic rules on stored data
- Provided as a free-issue item to the Supplier

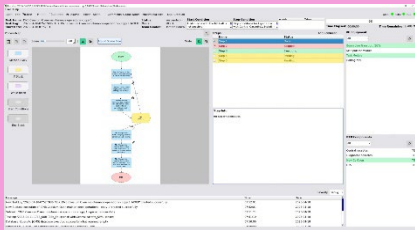


- HMI look and feel as the C&C
- Fast data acquisition mode
- Real-time display of data:
 - time domain plotting of data (trends)
 - frequency domain analysis (spectra)
 - amplitude domain analysis (histograms)
 - scatter plots
 - cross-correlation plots
- Recording and retrieval of monitored data in temporary and long term repository, either local/remote in HDF5 format.

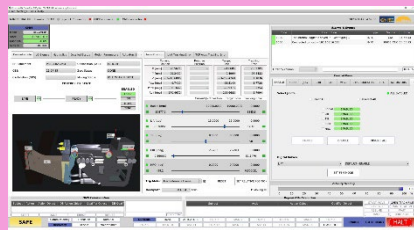
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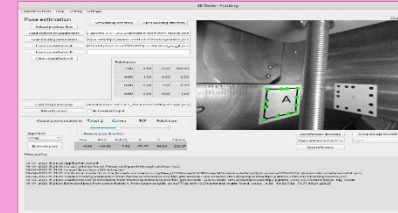


Virtual Reality (VR): to complement the Viewing System, to simulate **structural deformations**, to enable the anticipated detection of collision, to assist **Teleoperation**



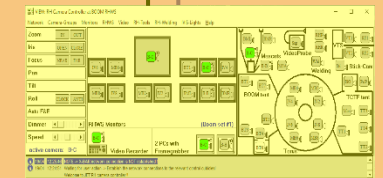
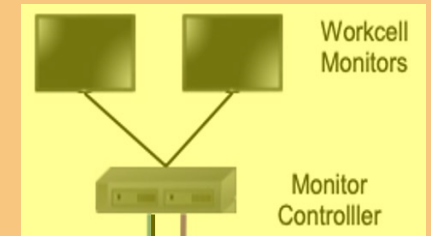
VIRTUAL REALITY SYSTEM

3DNode Machine Vision: to assist RH operations and Tele-operation.



RH OPERATIONS ASSISTANCE TOOLS

Viewing System (VS) for displaying camera views on the monitor displays of the RH workcell.



VIEWING SYSTEM

File Network

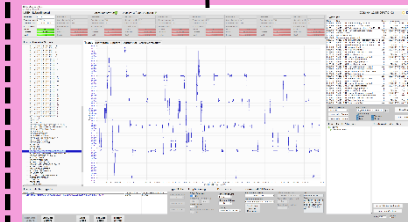
Emergency Stop button



Joystick



TASK SUPERVISOR



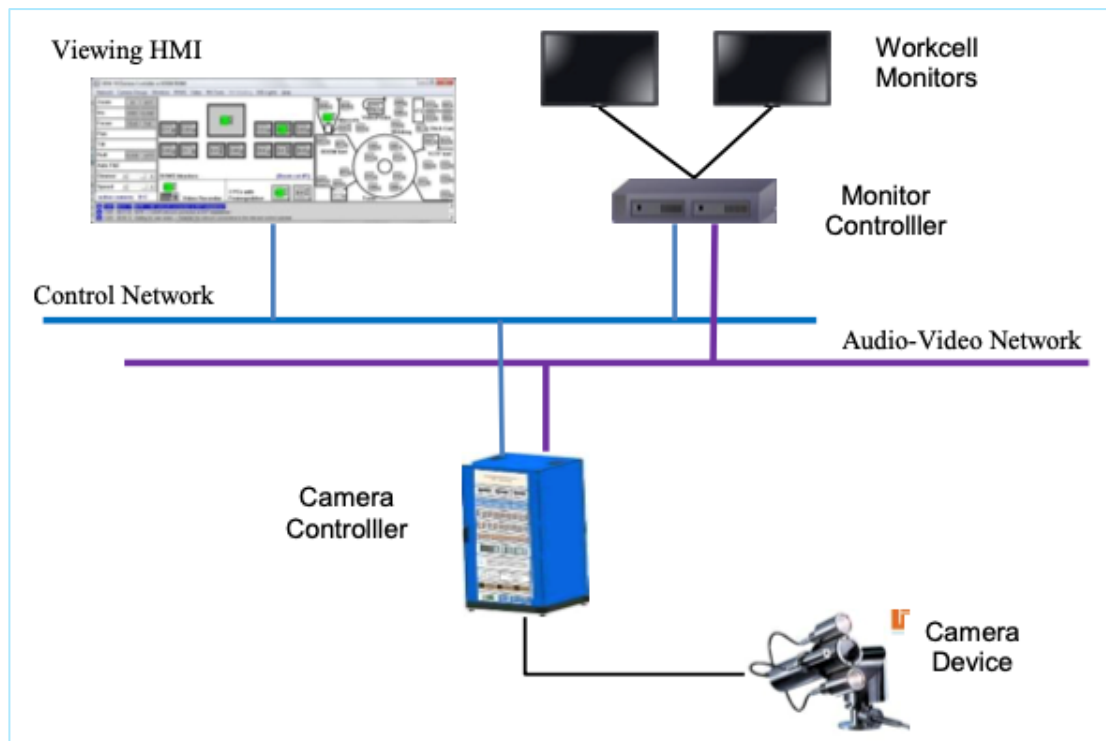
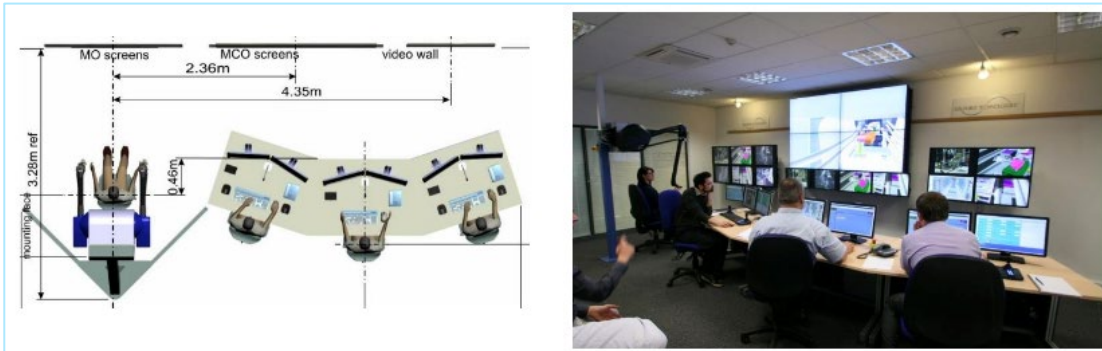
REMOTE DIAGNOSTICS

Remote Diagnostic System (RDS) enabling the monitoring of the equipment health status to detect degradation, anticipate and diagnose failures.

RH Control and Diagnostic Network

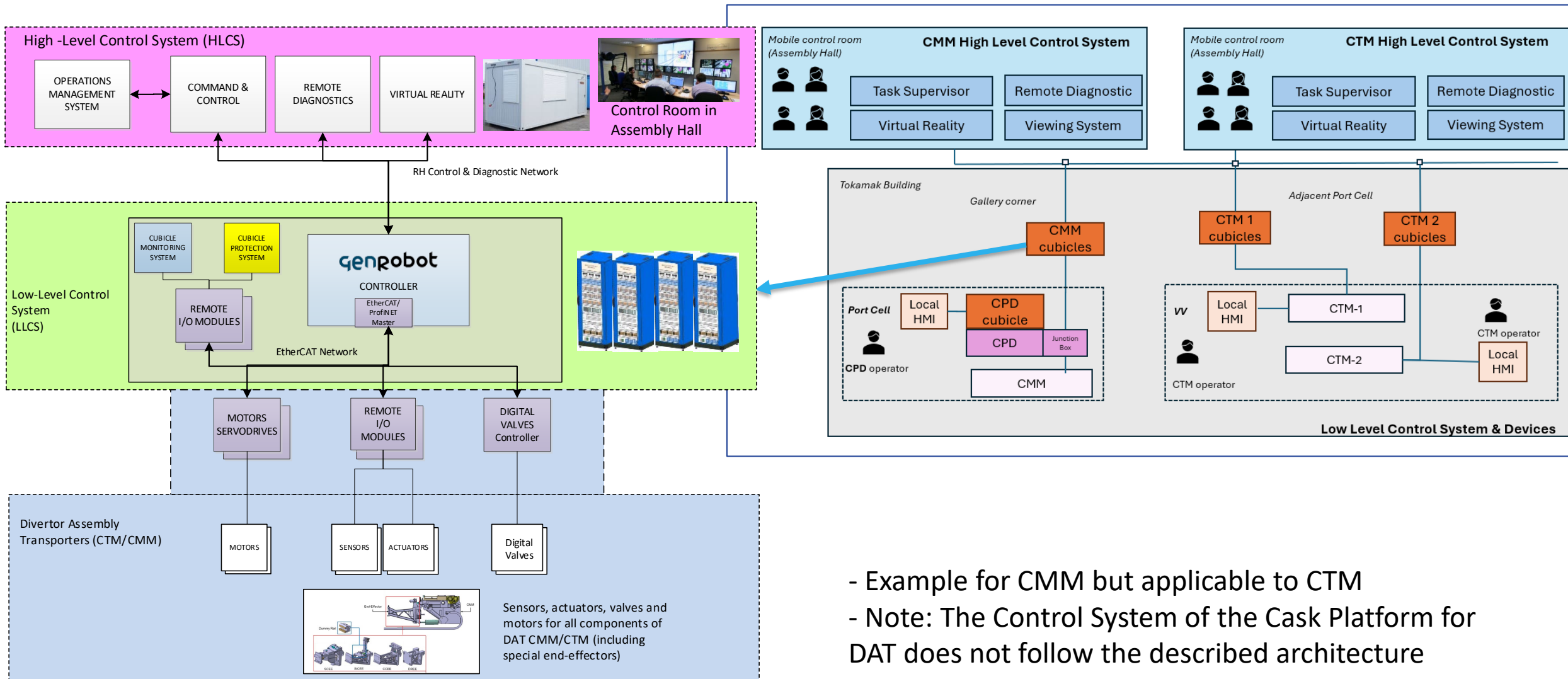
RH Audio-Video Network

RH Estop Network



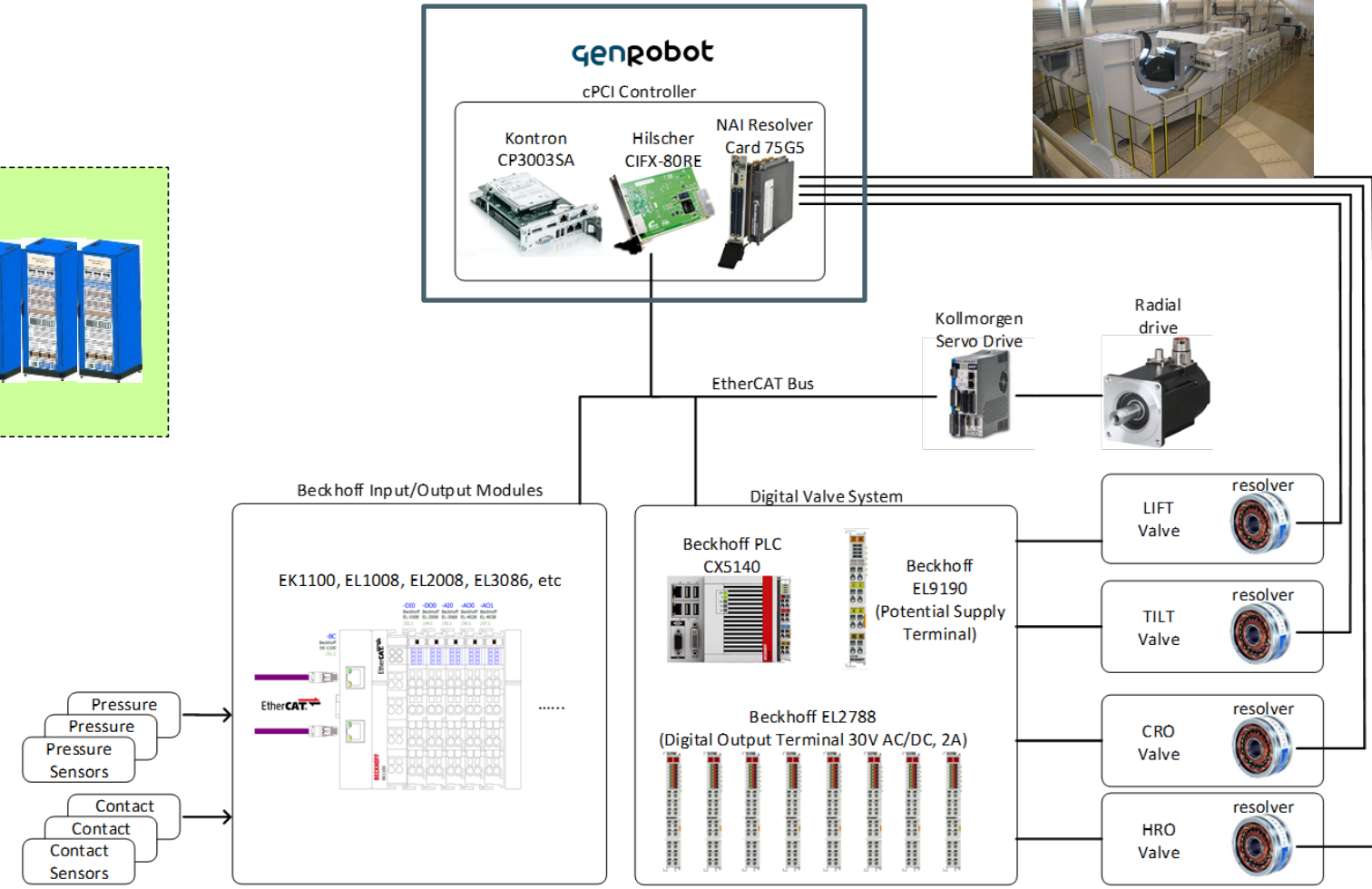
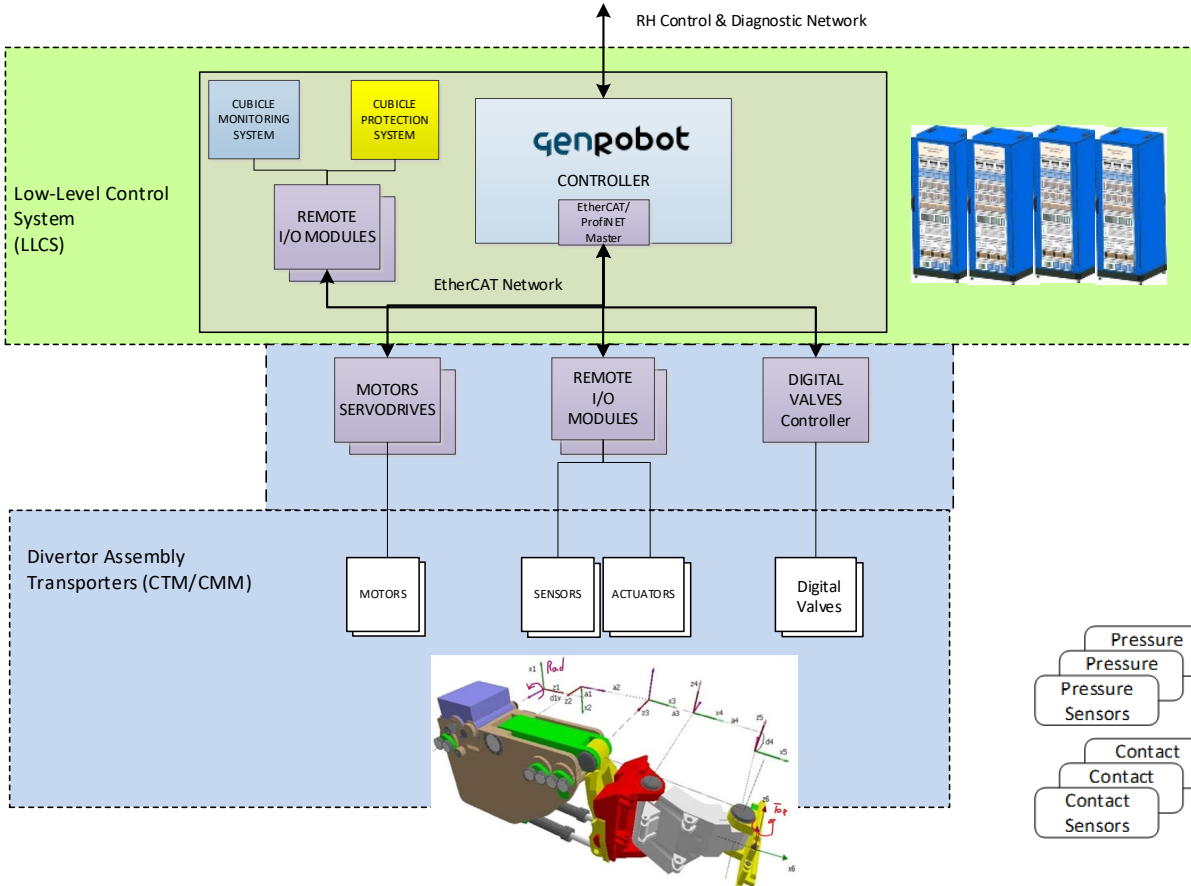
- Based on the OperView system COTS for real-time monitoring
- 2 possible configurations
 - Use of cameras over IP
 - Use of CoaxPress cameras controllers (not for DAT)
- Monitor controller:**
 - Video stream de-cropping, decoding and routing to workcell monitors
- Viewing System HMI:**
 - Selection and allocation of cameras to specific monitors commanding the monitor controller
 - Command cameras and monitor their status
- Latency performance requirement for remotely operating equipment:**
 - >100msec screen to screen

DAT Low-Level Control System for CMM (example)



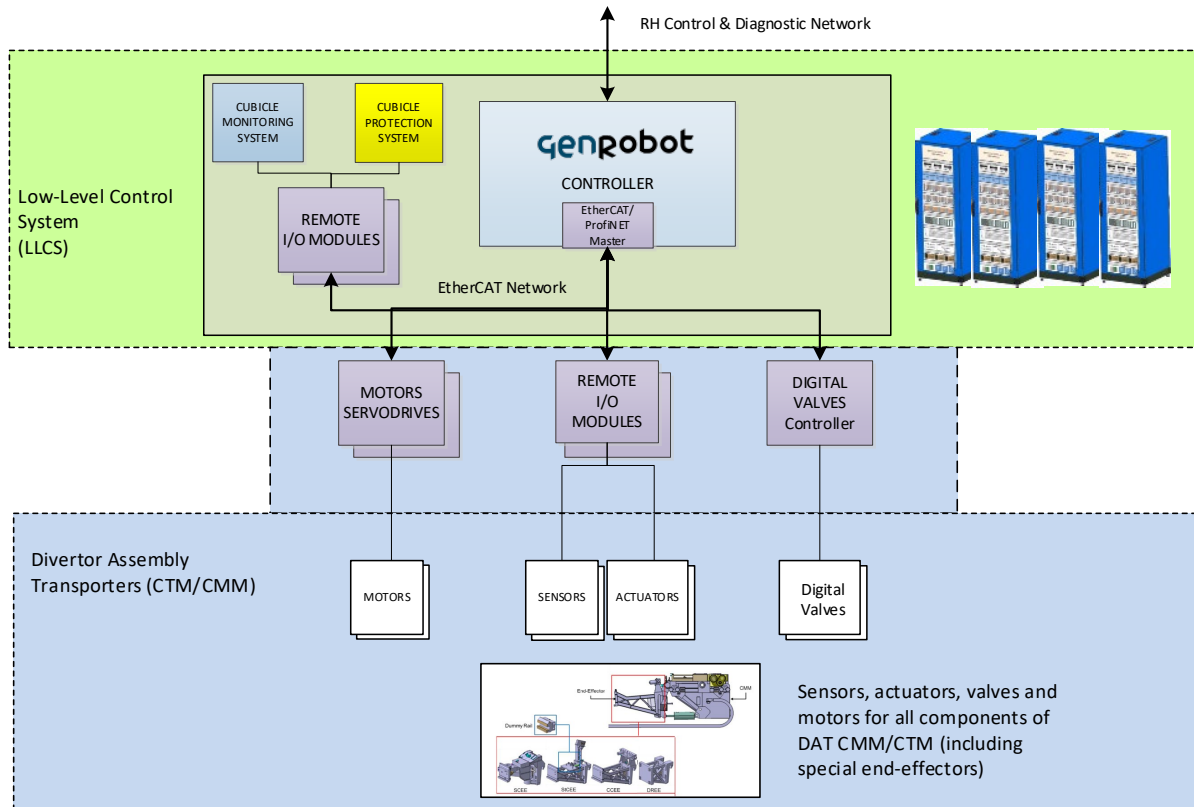
- Example for CMM but applicable to CTM
- Note: The Control System of the Cask Platform for DAT does not follow the described architecture

GENROBOT-based DAT Low-Level Control System for CMM @ DTP2



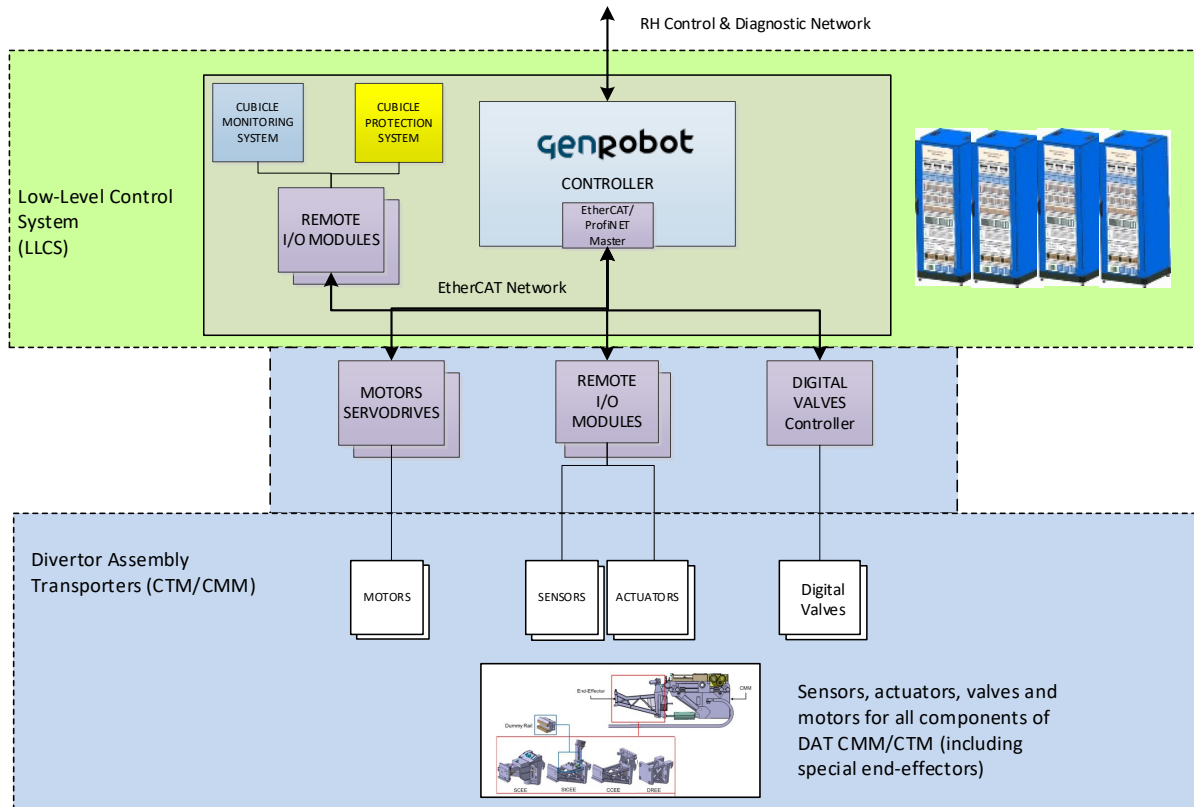
Digital Valve Controller (Bekchoff PLC with EtherCAT interface)

GENROBOT-based DAT Low-Level Control System for CMM (example)



- **GENROBOT is a Generic Software Robot Controller** for Remote Handling machinery (transporters, manipulators, end-effectors, tools)
- **Implementing all the common functionalities needed by RH equipment controllers:**
 - Cartesian and joint-level **move commands** (point-to-point, linear, JOG), buffers of commands, fly-by of move commands, motion settings (velocity, acceleration), on-the-fly velocity scaling, smooth/abrupt stop commands
 - **Ready to use network interfaces to C&C, VR, RDA and the RHPC** consisting of commands-replies, data subscription and publication at different rates, and alarm/warning/info events
 - **Ready to use low-level interfaces** to: protection circuit signals, motor drives, remote I/O signals, BiSS multiplexer controllers
 - **Recovery functionalities** by-passing sensory information, turning motor axes into simulated mode, on-line reconfiguration of motion control parameters
 - **Safety self-monitoring** and watchdog

GENROBOT-based DAT Low-Level Control System for CMM (example)



- It is **adaptable** to RH machinery through configuration parameters, drivers and user functions
- **GENROBOT is High quality and integrity software** compliant with IEC61508-3 industrial-safety standard
- Runs on the VxWorks 7.0 Operating System platform
- **GENROBOT is provided to the DAT Supplier as a free-issue item**
 - Pre-installed on a cPCI platform with CPU and EtherCAT master to be installed in the cubicle
 - With pre-adapted capabilities for DAT CMM and DAT CTM as hydraulics functions, interlocks, etc.
 - Needs parameters configuration and tuning to match hardware/mechanical components
 - Might need limited functional improvements requiring coding and compilation
- Pre-configured Digital Valve Controller provided as a free-issue item to be installed in the CTM/CMM
- Remote I/O modules to be bought & installed by the Supplier



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