REMOTE TOOL MONITORING SYSTEM

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As plant maintenance programs strive to improve plant efficiency, safety, and reliability, there is an increase in the use of automated tooling and systems. As a result, the need for a flexible and dependable remote monitoring system is evident. Atomic Energy of Canada Limited (AECL[1]) has designed a state-of-the-art remote tool monitoring system for the Pt. Lepreau Retube and upcoming Wolsong Retube. This system has the ability to view, to monitor, and to control numerous tools from site and from remote locations anywhere in the world. It consists of the Voice Communication System (VCS), the Video Observation System (VOS), the Retube System Software (RSS), and the Remote Retube Operations Centre (RROC). The VCS, VOS, RSS, and RROC work together to provide an unparalleled level of information on the tooling and refurbishment process which is not only useful during the refurbishment work, but also for operator training and future tool design.

I. Voice Communication System (VCS)

The Voice Communication System (VCS) is being used for CANDU[2] Retube operations and is currently in use at Bruce and Pt. Lepreau Generating Station (PLGS), and soon to be installed at the Wolsong Generating Station. The VCS enables communication among personnel inside the Retube Operations Centre (ROC), inside the reactor building and other specified areas such as the Crane Hall. The VCS will be used for the duration of the Retube project.

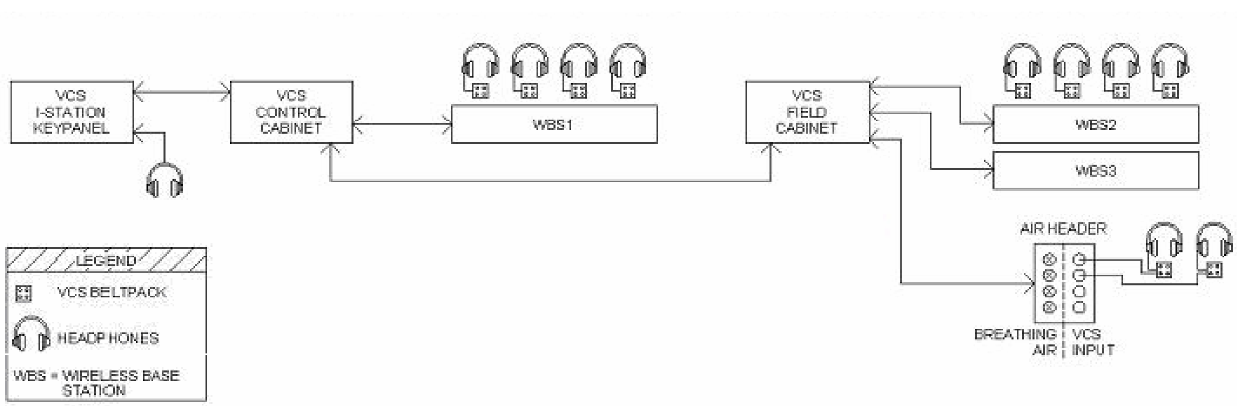

Figure 1: VCS Subsystem Overview

[1] AECL is a registered Trade-mark of Atomic Energy of Canada Limited
[2] CANDU is a registered Trade-mark of Atomic Energy of Canada Limited

The main components of the VCS consist of a digital audio matrix manufactured by Clearcom. The digital audio matrix enables a variety of audio nodes (ports) to be connected. The digital audio matrix is the brains of the audio system; it enables the user to communicate with and to switch between different nodes. Nodes are termination points where a user/headset is located. The digital audio matrix supports up to 208 full duplex (talk/listen) audio nodes and is configured with software. AECL engineers configured the system to support four different types of nodes. Details of the four main types of nodes are provided below:

Workstations

The workstations are access points for users that are inside the ROC, Radiation Protection Personnel and the VCS Operator. Each of the workstations has an audio connector (jack) that allows a headset to be plugged in. The workstation enables the user to quickly and easily access any user on the system by pressing a button on the workstation's keypanel or by calling the VCS operator. The buttons on the workstations may be programmed to light up in different ways (i.e. by colour and blinking speed) depending on the function, such as call waiting and in-use. The buttons may also be programmed to be fully duplex or half duplex (listen only or talk only). The light indicators and fully/half duplex functions are programmed during the software configuration process. Workstations that have an optional keypanel may also make outside calls just like a regular telephone. In addition, all workstations have the ability to record the audio through the VOS. Only one user is served by each of these nodes.

Wireless Nodes

The wireless nodes are primarily intended to be utilized while Retube personnel are not in plastic suits, but may also be utilized when they are in plastic suits. It should be noted that all Retube Operations are intended to be conducted without plastic suits. Hence, these wireless nodes eliminate a tether (and the need to untangle hoses) and enable personnel to freely roam the Retube platform—saving valuable time and radiation exposure by eliminating the need for personnel to have to carry a tether or to have to constantly plug in to a new VCS port as they move from one work area to another. Wireless nodes are located inside the reactor building and service building crane hall, but additional nodes may be placed at any other locations as needed. All users on a wireless base station are considered to be on a party-line. Up to four users are served by each of these nodes. Each wireless node consists of a wireless base station and four wireless belt packs manufactured by HME. The wireless base station operates in the 2.4 GHz range (a license-free bandwidth). The wireless base station utilizes FHSS (frequency hopping spread spectrum) which enables the wireless system to easily access a band that is not being used by another device. Since the system utilizes minimum bandwidth (approx 16 kHz) within the 2.4 GHz (2.400 GHz to 2.483GHz) range, the wireless system has over 4000 bands it can access. This will avoid interference and crosstalk within the VCS and from other RF (radio frequency) systems. The wireless belt packs also feature lithium ion batteries that have a 20-hour talk time and are extremely light-weight at 16 oz.

VCS Headers Nodes

The VCS headers are either modified existing air-breathing headers or new air breathing headers inside the reactor building which have additional connections to allow users to plug in a wired belt pack. The VCS headers are intended to be utilized while Retube personnel are in plastic suits, but the headers may also be utilized when they are not in plastic suits, as a backup to the wireless system. These headers are integrated into breathing air headers such that by plugging in the breathing air hose while in plastics suits the user will receive breathing air as well as the VCS. While not in plastic suits, the user may access the VCS by plugging in the wired beltpacks. Each VCS header node has four sets of receptacles; each receptacle can support one user. As a result each VCS header can support up to four users. Currently, these four users are on one channel, but the system could accommodate for each user to be on a separate channel. Furthermore, the VCS Headers will be a back-up system for the wireless nodes.

Special Nodes

These nodes provide VCS network access points to external systems that need to interface with the VCS. These external systems include the following:

1) Station Alert PA System: All messages on the Station Alert PA system shall also be broadcasted on all VCS networks

2) Phone Lines: The VCS shall be connected to outside phone lines
3) Radiation Personnel: The VCS shall be connected to Radiation Protection personnel.

Each of the above nodes will be able to communicate using conferences. A conference is defined as simultaneous communication among two or more nodes. The VCS operator is able to establish, abolish and change communication conferences. The VCS operators are also responsible for the routing of incoming "CALL" signals, outside telephone calls, and broadcasting information. Each of the above nodes is also able to "CALL" the VCS Operator by pressing the "VCSop" button on the workstation or the "CALL" button on the top of the wireless and wired beltpacks. As a result, a light will light up on the VCS operator's workstation, at which time the operator may answer the call and address the user's request.

Within the ROC, conventional Boom Microphone Headsets are used; however, in areas where hardhats are required, personnel are able to select from three kinds of hardhat headsets. One hardhat headset has a microphone boom, referred to as Boom Microphone Hardhat Headset (BHS). This headset is the default headset intended for regular use. The second hardhat headsets has a behind the head strap, referred to as Behind the Head Boom Microphone Hardhat Headset (WHS). This headset is required for welding operations or any operation where the hardhat clips are already occupied. The last headset is a throat microphone, referred to as Throat Microphone Hardhat Headset (THS). Throat microphones hardhat headsets will be utilized while personnel are wearing respirators. Personnel will no longer have to pull the respirator to the side of the face, inhaling unnecessary dose, in order to communicate with other personnel. All the headsets are interchangeable with the wired and wireless beltpacks and feature ergonomic gel headsets.

Overall, the VCS is an off-the-shelf product that makes the system, operating and maintenance cost effective. The system is easily expandable and may be easily configured to suit any application. With the wireless communication, personnel are able to roam freely and avoid unnecessary tangled hoses and cables, satisfying the demands of ALARA.

II. Video Observation System (VOS)

Like the VCS, the Video Observation System (VOS) is heavily relied upon during the PLGS refurbishment project. The first implementation for refurbishments was for the Bruce Units 1 and 2 retube.

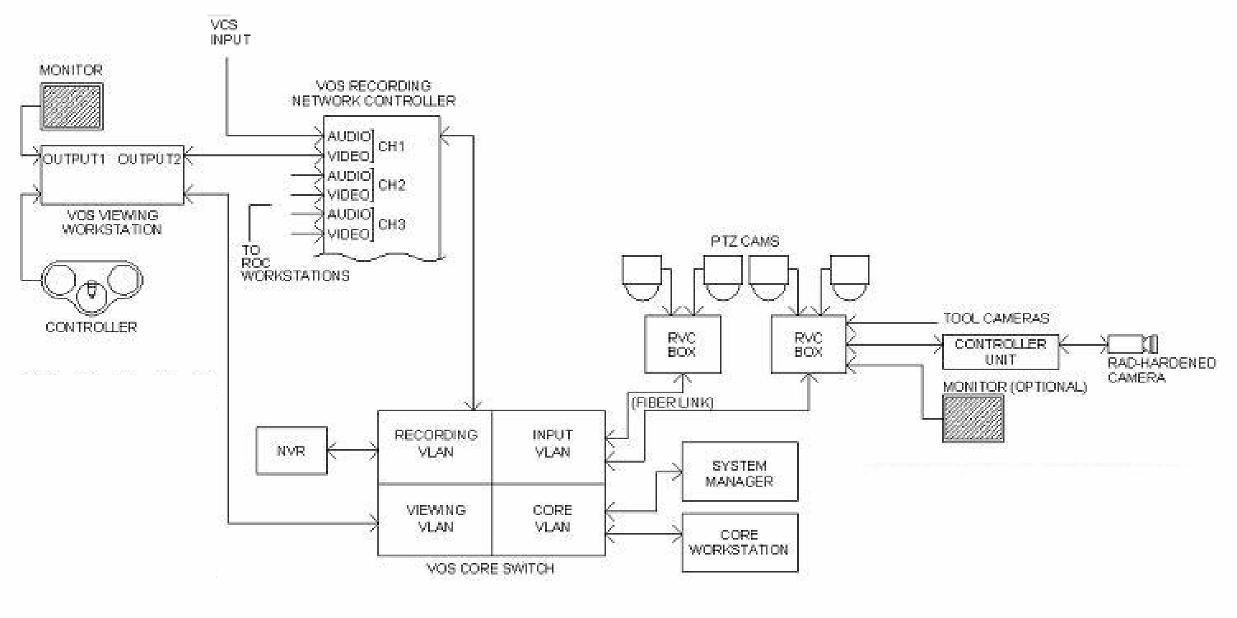

Figure 2: VOS Subsystem Overview

The VOS uses cutting edge IP video technology based on Pelco's industry leading Endura platform. AECL's VOS represents one of the first uses of Endura in Canada, and Endura is now being widely used for security monitoring in large companies and by many casinos. Unlike traditional analog based systems which rely on hardwired links from camera to a central matrix switching device, IP based video systems use an encoder to transform analog signals into MPEG-4 TCP/IP traffic which is then placed onto the VOS network. A decoder is needed to convert the video back from MPEG-4 to an analog signal that can be displayed on a monitor. The system uses Universal Plug and Play (UPnP) protocols to easily add or remove devices.

Any video signal that is encoded onto the VOS network can be routed to any monitor placed anywhere in the field, which gives operators the unique ability to easily route video into the vault.

Using an IP based video system provides AECL with increased scalability, flexibility, and redundancy. The number of cameras is limited by the bandwidth of the network, not by the number of ports available on a central matrix switcher. It is easy and inexpensive to add capacity for additional cameras and viewing workstations simply by increasing the number of network switches. In addition, integrating fiber to bridge long distances can be accomplished using fiber ports available on the network switches—thus eliminating the need for expensive and specialized video to fiber optic converters. However, the greatest benefit is that an IP based system allows the VOS to run on a distributed network. The failure of one device or node in the system—be it from equipment failure/damage or power loss—does not cause the entire system to go offline.

The VOS is designed to have separate networks for system management (core network), for camera input, for viewing and control, and for recording.

Core Network

The core network consists of three components: a gigabit layer 3 network switch (which may include either a series of linked switches or a single switch for smaller implementations), a system manager (SM), and a workstation for system configuration and maintenance purposes.

The core network switch uses Virtual Local Area Networks (VLANs) to separate the core network from other networks. Network traffic is effectively managed so that data broadcasted from devices in one VLAN will not flood the ports of devices on a separate VLAN. Therefore, the network switch is never overloaded and the video streams can be reliably routed with minimum network latency.

The system manager is a LINUX based server which stores the devices tables and network configurations of the VOS, provides DHCP addressing for devices, and works with the core switch to manage connected devices. The system manager is crucial when devices request IP addresses. However, once the network has converged, the network will continue to run in its last known configuration even if the system manager has failed or is powered down.

The workstation is a Windows XP computer that is used to configure devices and manage the system manager. During normal operation, users would never need to connect directly to the system manager, but can instead use the software on the workstation—reducing the chance the user accidentally corrupting the system manager.

Input Network

The VOS is configured with three or more camera input networks. Specialized nodes called Remote Video Control (RVC) boxes are used to connect between cameras in the field. Each RVC box consists of a set of encoders, a power supply to power up to 8 cameras, a decoder and built in monitor for displaying video, and a layer 2 network switch which is connected back to the Core switch via multimode fiber or CAT6 cable. Each RVC box can be plugged into a standard 120V/15A NEMA 5-15 outlet. A siamese cable with industrial connectors connects power and video signal to cameras directly to the RVC box.

Any camera with an analog output can be connected to an RVC boxes. For refurbishment projects, AECL uses Pelco Pan/Tilt/Zoom (PTZ) cameras. These compact cameras allow operators to pan 360 degrees continuously, tilt +/- 90 degrees or +/- 107 degrees (depending on the model), and provides up to 35X optical zoom capability with an additional 10X digital zoom. PTZ cameras are mounted using a reconfigurable magnetic mount, with the option for bolt-down mounting or pole mounting. In addition to the PTZ cameras, all tool-specific cameras that are powered by the individual tools are connected to the VOS network.

One of the unique features of the VOS is that high rad cameras manufactured by Imaging Sensing Technology (IST) Corporation can not only be connected but also controlled by the operators in the control room and on the vault floor. The ability to do so provides a seamless integration of all radiation tolerant cameras as well as eliminates the need for additional camera specific controllers. Operators need only to be trained on one system.

The RVC boxes and cameras allow the VOS to be a flexible, scalable system. While refurbishment projects use10 RVC boxes, operators may implement fewer or more RVC boxes as needed.. If there is a need for video monitoring in any location, all that is necessary is to run multimode duplex fiber to that location and to add an RVC box and cameras.

Viewing Network:

The viewing network consist of two types of devices: viewing workstations which allow the operators in the ROC and in the vault to view cameras, control cameras, and to view and export recorded video, and decoders which only output video with no control. The workstations provide ROC operators with the flexibility needed to monitor all refurbishment activities, while the decoders can be placed in conference rooms, or auxiliary control rooms where it is not necessary to control the cameras, but where an overview of the work areas is needed. Video is routed to the decoders via the workstation connected to the SM network. Using decoders to display video is useful to allow management and support staff to assess the conditions and work being done in the vault without the need to enter the ROC and disturb the operators.

Recording Network

The recording network uses a Network Video Recorder (NVR) to digitally store video of work activities. NVRs use RAID 5 arrays with a capacity of 4.5 Tb to 19 Tb, and additional storage can be added at any time should the need arise. Any camera on the network can be directly recorded; however, normally only the ROC viewing workstation outputs are recorded. This is because any camera being actively monitored by operators contains video that is relevant to the job. Since the VOS can handle 100+ cameras, depending on the work activities being performed, not all cameras will be viewing actual work activities at all times. Recording the workstations outputs is an effective means for the VOS recording network to filter the cameras in use from the cameras which may be idle—thus the VOS requires less storage space and personnel wishing to review the video can do so quickly without sorting through cameras that were not in use at the time.

The NVRs used for retube have the capacity to record a maximum of 48 inputs—each input can contain one audio input and one video input. When an operator reviews recorded video, he or she can also listen to any audio that was recorded along with that video. An audio link from the VCS for each ROC operator workstation is recorded along with the video recorded from that operator's VOS workstation. If there is a need to review the activities, operators can not only see what was being done, but can also listen to the communication between the ROC and the crews in the vault. This has already proven to be an asset for tool training.

The NVR will store 1 month of video on the system after which time the NVR will overwrite the older data. Any video that is required to be kept for a longer period of time can be exported either at the viewing workstation or from the SM workstation simply by connecting a USB hard drive or key. There is also the capability for taped back ups.

III. Retube System Software (RSS)

The retubing operation on the CANDU reactor is a series of complex tasks that involve the performance of parallel activities by different work teams. Monitoring and communication systems are required to ensure that the tasks are managed and performed safely, correctly and efficiently. The Retube Systems Software (RSS) along with the VCS and the VOS supports supervisory and quality control functions, and provides all functionality required for work management in the Retube Operations Centre (ROC).

The RSS is the first and only 3D HMI and SCADA system specifically designed and used in a CANDU refurbishment project and is powered by the Siemens FactoryLink development suite. RSS consists of three major subsystems: tool status monitoring, data acquisition and logging, and failover recovery subsystem.

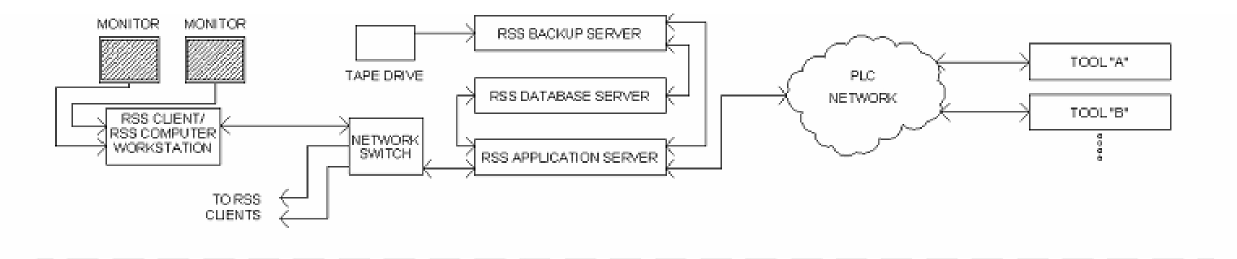

Figure 3: RSS Subsystem Overview

Tool Status Monitoring Subsystem

The RSS connects to the PLC controls network and can monitor the parameters for each tool connected to the network directly from the tool's controls system. For each tool connected, the RSS data acquisition system can handle up to 780 tags in real time, thus making it an asset for tool monitoring and troubleshooting. In addition to the tool status and raw data, the AECL RSS also contains an animated tool model in a 3D visualization environment.

2D HMI Display

The 2D HMI of the RSS offers an overview of the operating tool's status that could not be provided from the single traditional teach pendant (i.e. Siemens Mobile Pendant).
The RSS HMI displays the I/O status of all sensors, limit switches, and positions of the tool and alerts the operator if one or more of the values is out of range or unexpected. All information that is displayed on the tool operator's pendant in the vault is displayed on the RSS's 2D HMI. While the tool operator is running a pre-programmed sequence, the previous, current, and next steps will be displayed and logged in the ROC by the RSS.

For each servo motor the following parameters are continuously monitored: servo enabled, homed status, current position, torque, force, and velocity. For any hydraulic cylinders on a tool, parameters such as pressure, valve advance/retract are monitored. The system can monitor up to 16 servos and 16 cylinders per tool.

Real time trending can display any monitored parameter over time. For example the torque curve of a cutting wheel can be monitored to make sure that it displays the correct characteristics over the course of a cutting sequence. The parameters graphed can be dynamically selected to the best information visualization.

All alarms and warnings generated by the tool's control system are monitored from the RSS. ROC operators are notified immediately in the event of an alarm or warning, and will see the same information that the operators on the face see on the pendant. ROC operators can then help and direct work crews to rectify the alarm conditions. Alarms cannot be cleared from the RSS because an alarm or warning is generally an indication of a physical condition of the tool, and for safety reasons, only the tool operators can clear these.

3D Real Time Visualizations

The 3D real time visualization is the most unique feature of the RSS. The 3D RSS is designed to provide operators a variable perspective of tool. The 3D model used by the RSS is based on the actual 3D model that was created and used during tool manufacturing. Individual tool parts were highlighted or rendered transparent as needed to provide the best views possible.

The model can be manipulated in several ways while the tool is running: ROC operators can pan to a better view, rotate the tool model 360 degrees in the 3 axes, and zoom in on specific parts. There are default views that the ROC operators can switch back to instantly. The RSS will also show cross-sections and render select parts transparent so that operators and engineers can monitor and troubleshoot the inner workings of a tool.

As parameters are read from the tool's control system, the RSS will update the corresponding parts' locations on the tool model. The result is a 3D graphical representation of the tool that moves and changes in real time to show the exact position of the tool. If a ram extends, the ROC operator will see it extend. If the ram rotates or extends cutters while inside the calandria tube where it is out of view, the ROC operator will also be able to clearly see this on his/her 3D HMI screen.

These 3D viewing features are important to the retubing operation, because many of the tools are protected by heavy shielding, and often enter the calandria vessel to perform work inside the reactor. This is helpful when an operator cannot see exactly what the tool's internal mechanisms are doing with the VOS camera view of the tool. For example, it is impossible to see inside of the press of the Volume Reduction Machine. The operators and engineers would have to rely on feedback from the control system to determine the position of the press. The 3D RSS visualization is capable of providing a transparent view of the press, providing operators with a visual indication of what is happening (press position and operation) beyond the shielding.

A 3D Mobile HMI was designed to provide additional information of tool manipulation, which can be used to assist the tool operation. For example, the Calandria Vessel Inspection operator can see the current tool motion and configuration on the 3D Mobile HMI screen after the tool enters the calandria tube to perform inspection task. It provides extremely valuable information for navigating and manipulating the tool inside the vessel.

Real time 3D graphical representations like this greatly speed up the troubleshooting process, reduce unplanned events and can help operators to catch any issues before they escalate into bigger problems.

Each tool’s HMI is template-based and customized to provide clarity, usability and an intuitive user experiences. The following is the End Fitting Transfer Station HMI:

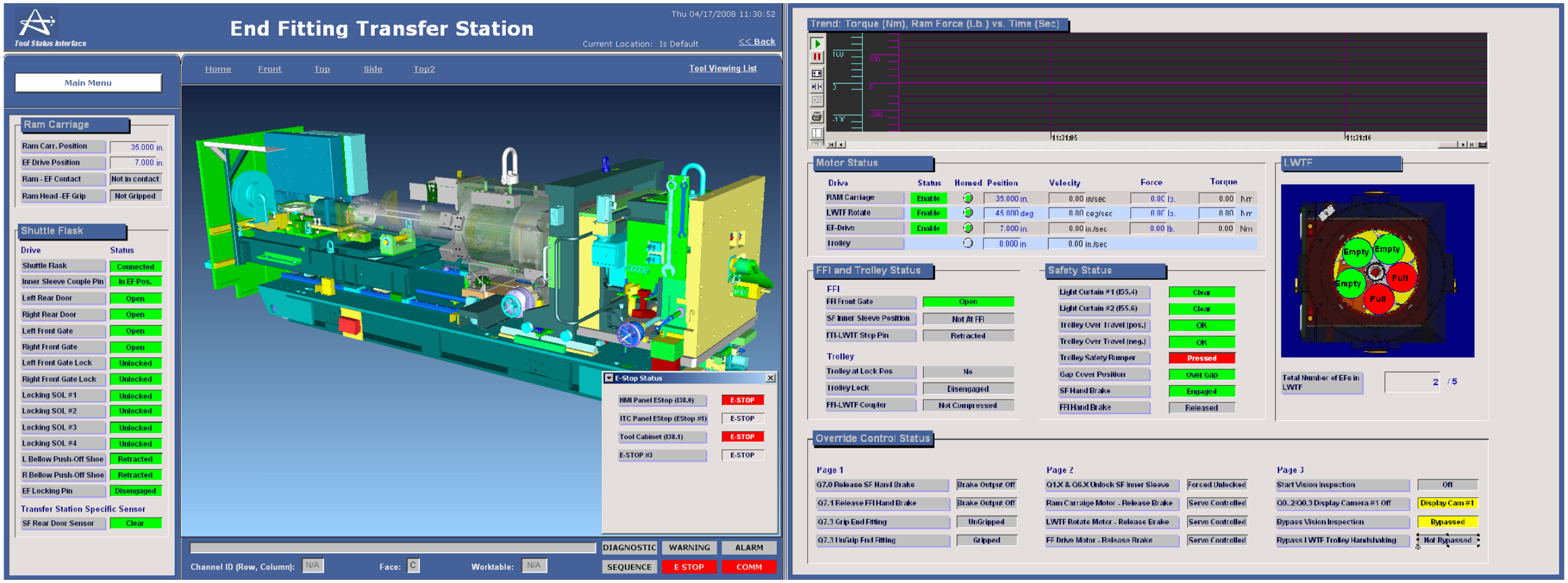

Figure 4: Typical HMI Layout

Data Acquisition and Logging Subsystem

As in any SCADA system, data acquisition and logging functions are heavily dependent on the network infrastructure. Therefore, the RSS Network Monitor application was designed to be implemented at the supervisory station in the ROC. To ensure the integrity of the network, this software application is used to monitor and report the networking status of all expected on-line control systems, the RSS servers, and the client workstations during the operation. The supervisor will be alerted if there is any unexpected network communication loss.

The RSS is using the S7D native driver from Siemens FactoryLink to acquire data from the control systems in the vault. All the online tool statuses are logged on the RSS database server with one-second interval. The RSS database supports up to 7 days of data storage online. The RSS also backs up all data generated by the tools' control systems. Data is written to tape drive system every night. Tapes are cloned once a week to protect against tape corruption, and all backups are stored off site. The data recorded to tape allows engineers to review the tools performance and aids in troubleshooting. The data can also be taken into consideration to determine if the tool was functioning as expected, if the forces required to perform an action were as expected, and to identify areas where the tool can be improved for future builds. Additional enhancement allows the logged data to be replayed by the RSS, providing a tool animation playback feature. All sensors readings/statuses and 3D model visualizations will respond exactly as if connected to the actual tool's control system—except the RSS in this case will be reading historical data from the database and not from the field. Coupled with the recorded video and audio, this allows AECL to provide an unprecedented level of training for new operators. It also allows engineers to have the most complete information when reviewing the work sequences.

Failure Recovery Subsystem

The RSS software components and technologies were selected from vendors (i.e. Siemens, EMC, HP and Microsoft) known for a reliable and a secure supply of software maintenance and support, provided that the choice did not compromise the efficiency and accuracy of operations. The design includes features to allow robust operation in spite of user input errors, and in spite of failure of systems interface with the RSS subsystems.

The RSS server configuration consists of an application server, database server and backup server. The following is the layout of the RSS server system:

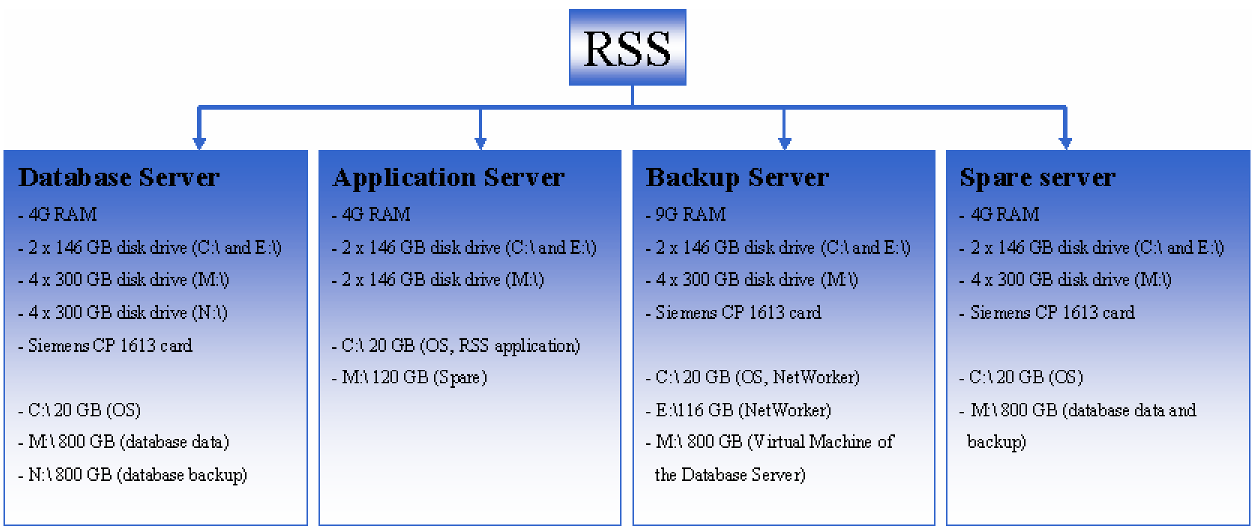

Figure 5: RSS Server System Layout

The backup server is designed to handle single failures of the RSS server system. For example, when one or two of the servers fail, the backup server can be used as a temporary recovery server. The backup system is using NetWorker software from EMC to perform server failure recovery. A complete set of the server images is regularly generated by the ROC maintenance team for the preparation of extensive failure recovery. Using the RSS failure recovery manual, the trained ROC maintenance team could simply recover the entire RSS failover system.

IV. Remote ROC (RROC)

The tool monitoring system as described functions in the Retube Operation Centre (ROC) and within the plant where refurbishment activities are ongoing. However, it was also designed to incorporate the Remote ROC (RROC) which is an interface that allows the tools to be monitored from anywhere in the world.

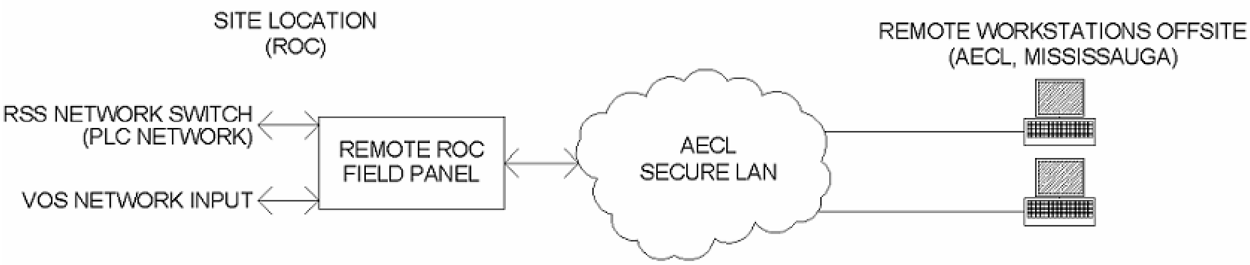

Figure 5: Remote ROC Subsystem Overview

The RROC provides a gateway to the RSS, PLC network, and VOS over an AECL secure LAN connection. The VCS has channels that are assigned phone numbers and allows a remote location to place a call over the standard telephone system and to be patched into the VCS. Using these features, AECL has setup a remote monitoring facility at the Mississauga location where an operator can view live video, view live RSS tool data, connect to the tool's PLC network, and call into the VCS system. In addition to using an AECL secure LAN, all connections using the RROC are protected by robust passwords.

The RROC feature greatly enhances the level of support that the AECL engineering and tooling group can provide to a site. Today AECL engineers and technicians are able to monitor and help troubleshoot the Point Lepreau refurbishment activities in New Brunswick from Mississauga, Ontario. With the proper network connections in place, the engineering and tooling group in Mississauga can use the RROC to monitor refurbishment activities anywhere in the world including at the Wolsong site in Korea.

The RROC is useful for helping to answer questions from site and for troubleshooting any issues should they arise. In many cases AECL technical experts were able to quickly assess and answer questions using the RROC—thereby eliminating the need to send resources to a site—greatly increasing the efficiency of the project while reducing delays and costs. Tool manufacturers based in the GTA and surrounding area can be brought into the RROC to assess tools within hours as opposed to spending days traveling to and from site.

V. Operational Experience (OPEX)

The tool monitoring system has already proven to be an asset during the early stages of the Point Lepreau Refurbishment. Some examples include:

- Network, Interlock and Safety Monitoring

  During a bridge movement an e-stop button was left activated. Using the RSS, engineers in the ROC were able to view the status of each connected tool with active interlocks from a central location and quickly determine which e-stop was on. Using the VOS, ROC operators were able to visually verify that the identified tool's e-stop was pressed, before sending operators to the tool panel in question to de-activate the e-stop. Operators were guided by the ROC by means of the VCS. Without the RSS, operators in the vault would have had to check each tool's pendant and control cabinet. In this case the use of the tool monitoring system saved the project time and dose.

- Work Assessment and Planning

  At the shift changeover meetings, shift managers, outage managers, and tool leads routinely use the VOS displays in the conference room to confirm work progress. The live visual display aids in discussion of work to be accomplished. This system allows elimination of unnecessary trips to the vault and exposure.

- Remote Troubleshooting and Observation

  During the first use of an automated tool to remove closure plugs, AECL tool engineers in Mississauga were able to use the RROC to observe the tool in use. They were connected through the VCS using a standard telephone line, and could view video of the actual site using the remote connection to the VOS. Tool forces and torque values were obtained from the RSS to confirm that tool was functioning correctly.

VI. Conclusion

The remote tool monitoring system, consisting of the VCS, VOS, RSS, and RROC, is a very powerful system providing operators at site and engineers/experts at remote sites with the capability to monitor refurbishment activities. The tool monitoring system also gives AECL the ability to efficiently train new operators with actual tool data and sequences. Lastly, the system has saved valuable time and expenses eliminating unnecessary travel to site for support services, which in the case of Wolsong in South Korea will have extensive financial benefits.

The Tool Monitoring System is robust, reliable, flexible, expandable and for the most part is built using widely available off-the-shelf components adapted to the unique requirements of the nuclear industry. The system can reduce the time needed to troubleshoot a tool by letting operators observe accurate and up-to-date information. Technical experts can access the system from anywhere in the world – which in turn can reduce the duration of an outage activity and occupational radiation exposure. The system will help assess unplanned events and minimize unexpected costs by presenting all relevant information in a flexible operator-friendly manner.

Appendix A: Remote Tool Monitoring System Overview

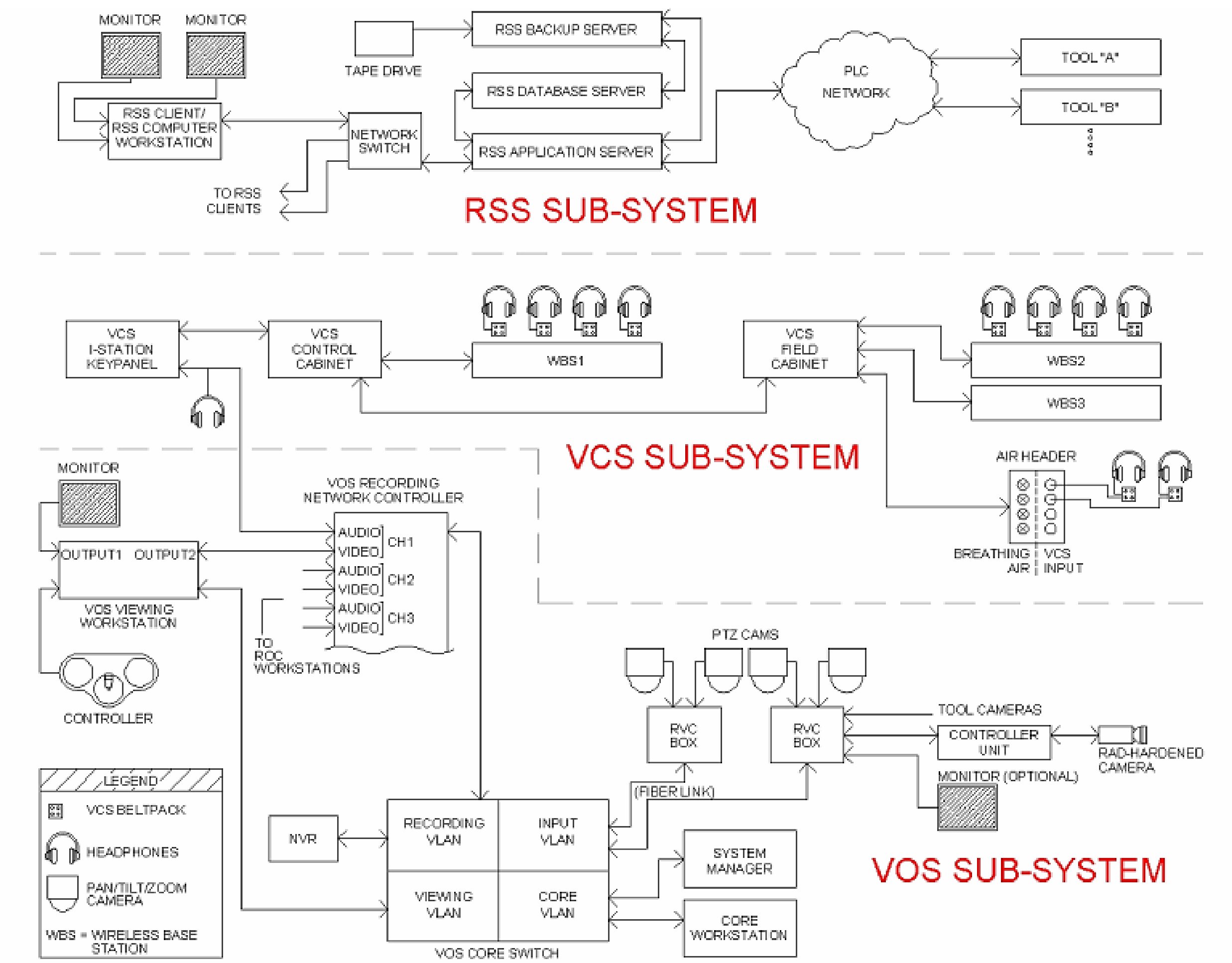

Figure A-1: ROC workstation overview

Typical ROC operator workstations consist of an RSS client workstation, a VCS workstation, and a VOS workstation. These workstations allow operators to have tool feedback, video, and audio communication with the vault.

The RSS application server is connected to a database server for data logging, and both are linked to a backup server. In addition to performing scheduled tape backups, the RSS backup server can also temporarily assume the functions of the application and database servers to add redundancy to the system. The application server is directly connected to the PLC network which allows it to gather the tool operating parameters.

Each VCS station has a keypanel to allow operators to switch communication between different groups in the vault. Wireless base stations or modified breathing air headers are placed in the field and linked back to the VCS control cabinet using multimode fiber.

The VOS workstation consist of a VOS specific computer, monitor, and a controller which allows operator to switch camera views and to control PTZ cameras. Cameras in the field are plugged into the nearest RVC box and linked to the core network switch using multimode fiber. The core switch is segregated into VLANs to efficiently route traffic. The recording network records the video that the operator is viewing on his or her workstation; in addition, the recording network also accepts VCS inputs so that the audio can be recorded and later reviewed.