A Distributed Control Architecture for Advanced Testing In Realtime

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ABSTRACT

Distributed control architecture is based on sharing control and data between multiple nodes on a network. Communication and task sharing can be distributed between multiple control computers. Although many communication protocols exist, such as TCP/IP and UDP, they do not have the determinism that realtime control demands. Fiber-optic reflective shared memory creates the opportunity for realtime distributed control. This architecture allows control and computational tasks to be divided between multiple systems and operate in a deterministic realtime environment. One such shared memory architecture is based on Curtiss-Wright퐐 ScramNET family of fiber-optic reflective memory. MTS has built seismic and structural control software and hardware capable of utilizing ScramNET shared memory, opening up infinite possibilities in research and new capabilities in Hybrid and Model-In-The-Loop control.

1. Introduction

Although reflective shared memory architecture has existed for some time, it is a relatively new advance in seismic and structural control. This architecture is based on a reflective memory ring, where multiple systems can share data with delays in the nanosecond range. This low latency and determinism is critical for seismic and structural control, since feedback loop stability degrades with any appreciable delay.

Although MTS has been developing advanced seismic and structural control systems for 30 years, only recently has reflective memory capabilities been packaged into their control systems. This has opened up significant advances in research and testing: developing hybrid testing and simulation in the loop modeling, researching new control techniques, and distributing critical control tasks to other systems.

2. Reflective Memory

Closed-loop servo-hydraulic control requires deterministic, repeatable, high-frequency sampling of feedbacks in order to adequately control large physical systems. MTS has typically used a Host-Target configuration that partitions tasks in a manner such that all time-critical tasks are assigned to a Realtime Target, and non time-critical tasks to a Host PC. Time-critical tasks run within a realtime OS environment on the target machine since it provides a much more deterministic and stable operating environment than standard PC operating systems such as Windows or Linux.

The Host-Target communication has typically been TCP/IP Ethernet driven. Since TCP/IP is a software protocol, network latencies on the order of hundreds of milliseconds can be fairly common due to the need to pack, queue, transmit, route, de-queue, and unpack data. Typical loop rates for seismic testing are on the order of 1024 Hz. But since time-critical operations reside entirely within the realtime target machine, any host-target latencies can generally be ignored or compensated for in the Host.

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But using a TCP/IP Ethernet network architecture to access to time-critical data in the realtime target has significant drawbacks. Any non-deterministic communication into the realtime system could cause delays to the critical control. With the inclusion of reflective memory, access to the realtime target can now be realized without affecting the deterministic demand of the target machine.

Reflective memory is based on shared memory nodes distributed through a closed ring or daisy-chain configuration (Figure 1). The memory is accessed through the hardware bus, in a PCI, PME or cPCI format. Since the ring is completely hardware communication driven, significant speed advantages can be realized.

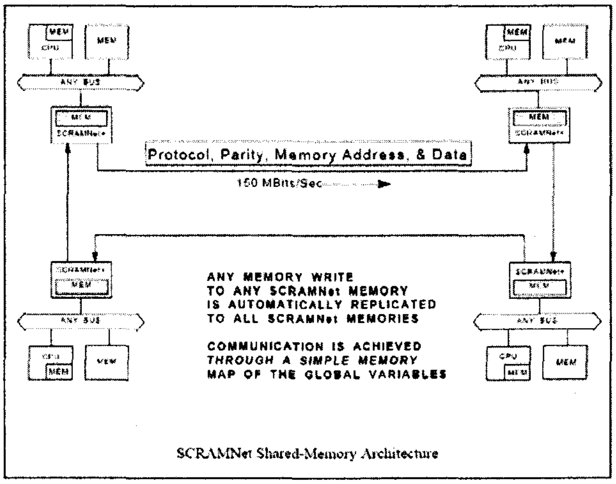

Figure 1: ScramNET ring configuration (Curtiss-Wright, 2006)

Although several vendors of shared memory exist, MTS chose the Curtiss-Wright휠ScramNET product (Curtiss-Wright, 2006). Some key elements of the ScramNET reflective memory are:

- Messages are fixed in length; 82 bits long.
- The ring access time is between 100 nanoseconds and 800 nanoseconds.
- The node latency time is between 250 nanoseconds and 800 nanoseconds per node.
- Nominal delays are around 250 nanoseconds.
- Propagation delay incurred in transmission media is 5 nanoseconds/meter of cabling.
- Bit error rate is extremely low due to fiber-optic transmission.
- Is available in a variety of form factors and memory sizes (Figure 2).

Series Number	Environmental Requirements	Memory Sizes	Interrupts Available/ Error Detection	Transmission Medium	Performance	Memory-to-Host Transfer Rate	I/O Support														
							Bus Type	HP-UX	QNX (on Intel Architecture)	Red Hat Linux	SGI IRIX	Sun Solaris	SUSE Linux	VxWorks	Windows 98	Windows 2000	Windows Me	Windows NT	Windows Server	Windows XP	Yellow Dog Linux 2.1
SC150	Operating Temperature: 0° to 60° C, 32° to 140° F Operating Humidity: 10% to 90% (noncondensing)	1 MB 2 MB 4 MB 8 MB	Yes	Coax (up to 30 meters) Standard Fiber (up to 300 meters) Long-link Fiber (up to 3,000 meters)	150 Mbit/sec Bit Rate 16.7 MB/sec Network Transfer Rate 250 nsec Min Node Latency	Up to 16.7 MBytes/sec	PCI	x	x	x	x	x	x		x	x	x	x	x	x	
							VME6U							x							
							Rehostable	User Defined Interface													
SC150e	Electrical Universal +5/3.3 VDC Operating Temperature: 0° to 60° C, 32° to 140° F Operating Humidity: 10% to 90% (noncondensing)	2 MB 4 MB 8 MB	Yes	Standard Fiber (up to 300 meters) Long-link Fiber (up to 3,000 meters)**	150 Mbit/sec Bit Rate 16.7 MB/sec Network Transfer Rate 250 nsec Min. Node Latency	Up to 70.0 MBytes/sec	PCI	x	x	x	x	x	x		x	x	x	x	x	x	
							CompactPCI	x	x	x		x	x		x	x	x	x	x	x	
							PMC		x			x		x							x

Figure 2: ScramNET technical specifications (Curtiss-Wright, 2006)

3. Control Hardware

3.1 MTS Seismic and Structural System Hardware

MTS uses its Model 493 family of control hardware to implement seismic and structural control systems. As shown in Figure 3, the 493 hardware consists of a realtime digital signal processor, sensor conditioners, A/D converters, and servovalve drivers tied together on a VME bus backplane. Basic system control in implemented within the confines of the 493 VME chassis. Advanced control is implemented in a PC external to the 493, shown in Figure 3 as 밟C Realtime Target? This PC is used to implement higher level control such as model-in-the-loop algorithms, as well as integrating control feedbacks with other specimen feedbacks for data acquisition purposes.

Signals pass between the 493 controller and the PC Realtime Target via ScramNET. A ScramNET PMC card is installed on the mezzanine bus of 493 processor, and a ScramNET PCI card is installed on the PC퉩PCI bus. Via ScramNET, the PC Realtime Target has direct access to all 493 controller signals, and vice versa. In addition, the PC Realtime Target can develop and pass command signals to the 493 processor.

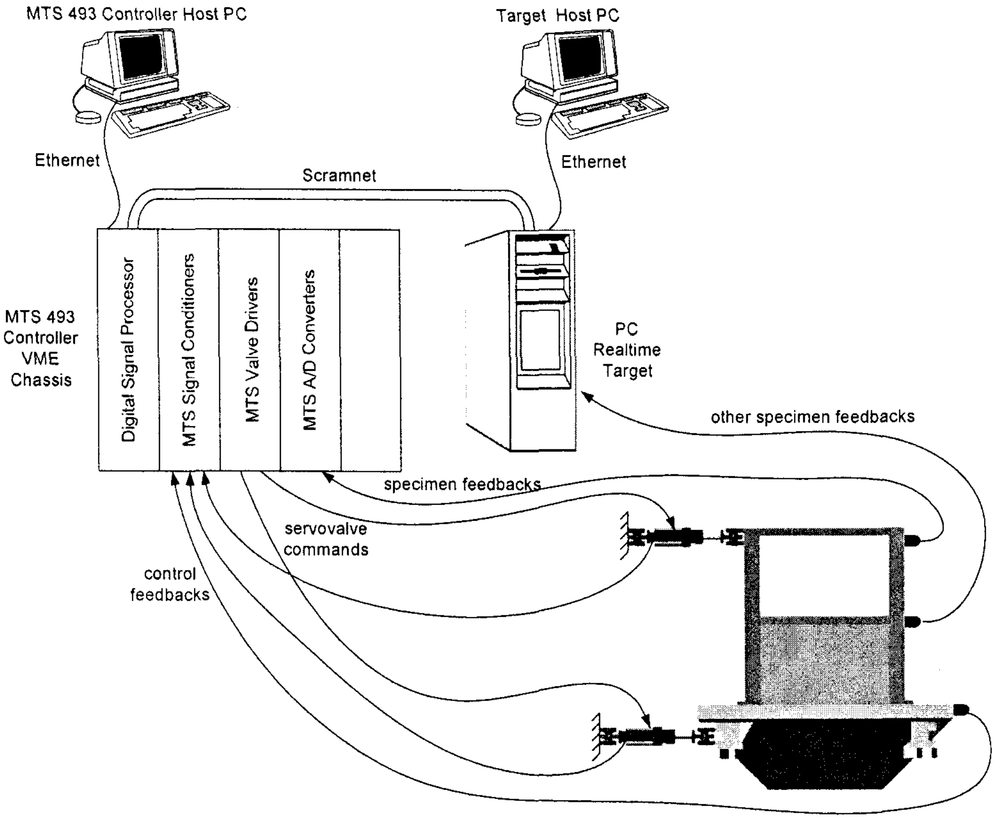

Figure 3: Typical MTS distributed control system hardware configuration

3.2 PC RealtimeTarget Machine

Once a ScramNET PCI card is installed, any PC (or any number of PCs) can be used as a realtime target machine. By adding third-party analog and digital I/O boards to the PC, all devices on the ScramNET ring can have access to these additional signals.

3.3 cPCI Target Machine

Any National Instruments PXI Chassis (National Instruments, 2006) can be used as a realtime target machine. National Instruments offers a host of data-acquisition hardware for the PXI platform. Thus the reflective memory ring can have access to measured data and DIO through N.I. hardware.

4. Control Software

4.1 MTS Seismic and Structural System Software

MTS has integrated reflective memory into two configurations of its control software, the first being the 469D control software currently in use on seismic systems. This software has been in development and use for over 10 years in seismic systems worldwide. To allow read/write access to the reflective memory node in the realtime target, the software has been modified to allow the reflective data to be used a command source, similar to the standard function generator, data-player, and external analog features. A simple selection by the operator allows the realtime software to read the reflective memory allocated for command data, and use this data as the command to the seismic system.

MTS has also integrated reflective memory into its STS (structural test system) software, which is optimized for structural testing. This software implements PID control and allows mode switching between load and displacement control.

For all nodes on the reflective memory ring to update at the same time, a master clock is needed. Since the MTS controller is the primary controller and demands command updates to occur at its set clock rate, it is designated as the master clock. The 469D software sends an IRQ (interrupt request) out on the reflective memory ring. Each node on the ring receives the IRQ and reads/writes to the allocated memory at that instant. Therefore all nodes on the ring are clocked in sync to the MTS controller.

4.2 Mathworks Simulink Simulation Environment

The Mathworks? Simulink is the de facto standard software environment for dynamic system modeling, experimentation, and control algorithm development. When combined with The Mathworks? Real Time Workshop, Simulink models can be compiled into realtime code and downloaded to a realtime target processor. Simulink drivers exist that allow read/write access to all the memory blocks on the ScramNET ring. Real Time Workshop requires a Host-Target configuration in order to run Simulink models in realtime. The Simulink Host communicates with the target over a TCP/IP Ethernet connection. Figure 4 shows an example of this software architecture.

4.3 National Instruments LabVIEW and LabVIEW Real-Time Simulation Environment

National Instruments LabVIEW and Real-Time Software provide ScramNET drivers that also allow read/write access to the reflective memory ring. National Instruments has extensive data acquisition capabilities, as well as control and analysis libraries. LabVIEW also requires a Host-Target configuration for implementation of reflective memory, using a TCP/IP Ethernet connection to communicate to the realtime target. The realtime target can be either a PXI Chassis with a cPCI ScramNET or a standard PC with a PCI version. Both are booted using LabVIEW realtime software, and both allow read/write access.

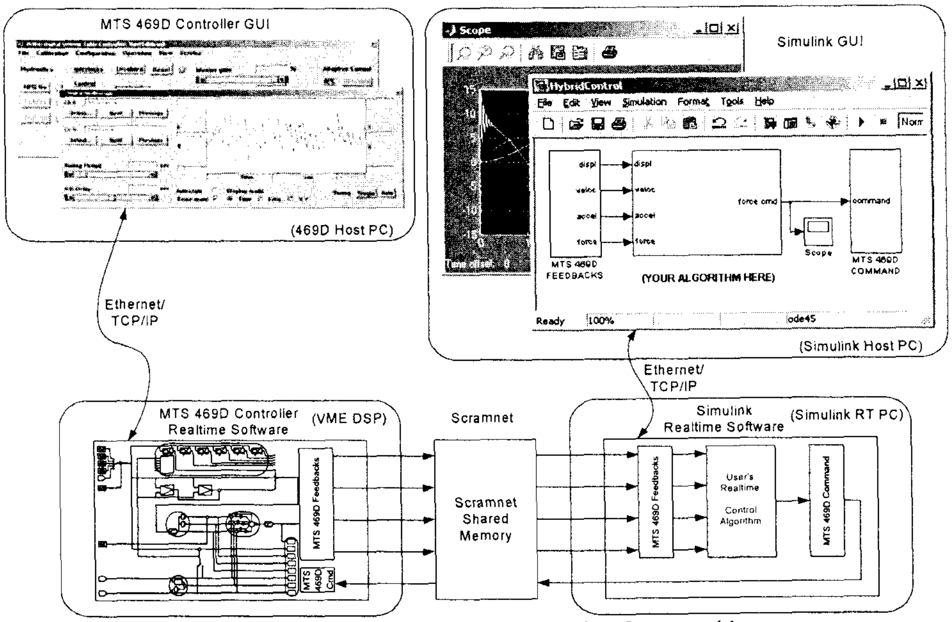

Figure 4: MTS and The Mathworks Simulink software architecture

4.3 Other Simulation Software Environments

Simulating a structure in the control loop with reflective memory can be implemented in other ways. Open System for Earthquake Engineering Simulation (Open SEES) is an object-oriented finite element software developed at the Pacific Earthquake Engineering Research Center (PEER) at the University of California, Berkeley (OpenSEES, 2006). OpenSEES can be implemented on a realtime target PC and allows read/write capability on the memory ring. OpenSEES has an extensive element library that can be used for structural modeling.

5. Hybrid Capabilities

Realtime hybrid simulation is a method to determine the response of a structure to dynamic excitation. Hybrid simulation is unique since the simulation is composed of one or more physical models and one or more numerical models. Typically, a portion of a structure is attached to a shake table or servo-hydraulic actuator while the rest of the structure is modeled numerically (Figure 5). It is this demand for connectivity between the real and numerical models and the demand for realtime speed, minimum delay, and deterministic operation that requires reflective memory architecture.

A basic Hybrid installation requires a seismic or structural controller and a simulator. The controller is typically the MTS 469D seismic or STS system controller. The simulator can be any of the latter software-hardware combinations. Typically, the simulator is used to represent the numerical portion of a structural system while the controller drives the real portion. It is the reflective memory ring that completes the connectivity, allowing the system to behave as one global simulation.

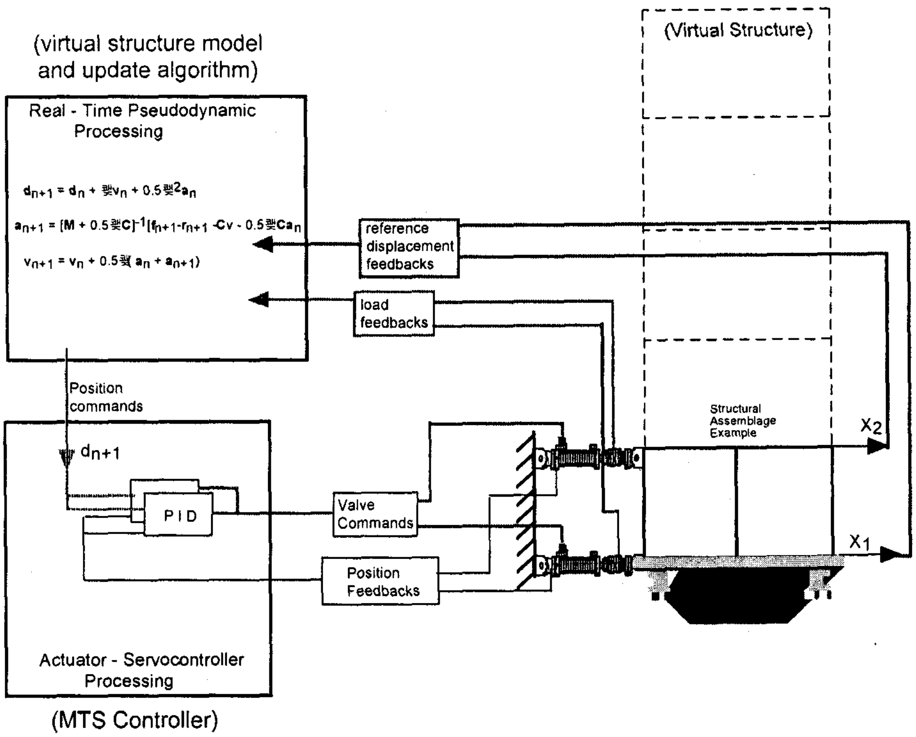

Figure 5: Typical Hybrid System

6. Example Hybrid Installation

The George E. Brown Network for Earthquake Engineering (NEES) has several hybrid sites: UC Berkeley, University of Colorado at Boulder, Lehigh University, and SUNY Buffalo.

MTS completed an installation at SUNY-Buffalo in 2005 that represents a state-of the art realtime hybrid-seismic installation (Figure 6). The site was developed to conduct testing of full or large-scale structures using static or dynamic loading and earthquake simulations. The site has the capability of modern testing techniques, such as Realtime Dynamic Hybrid Testing and Pseudo-Dynamic Testing, along with conventional Static, Quasi-static, and Dynamic Force techniques. A new form of dynamic substructure testing, Realtime Dynamic Hybrid Testing developed at the university, combines shake table and/or dynamic force experiments of substructures with realtime computer simulations of the remainder of the structure. This provides a more complete picture of how earthquakes would affect large structures, including buildings and bridges, without the need to physically test the entire structure.

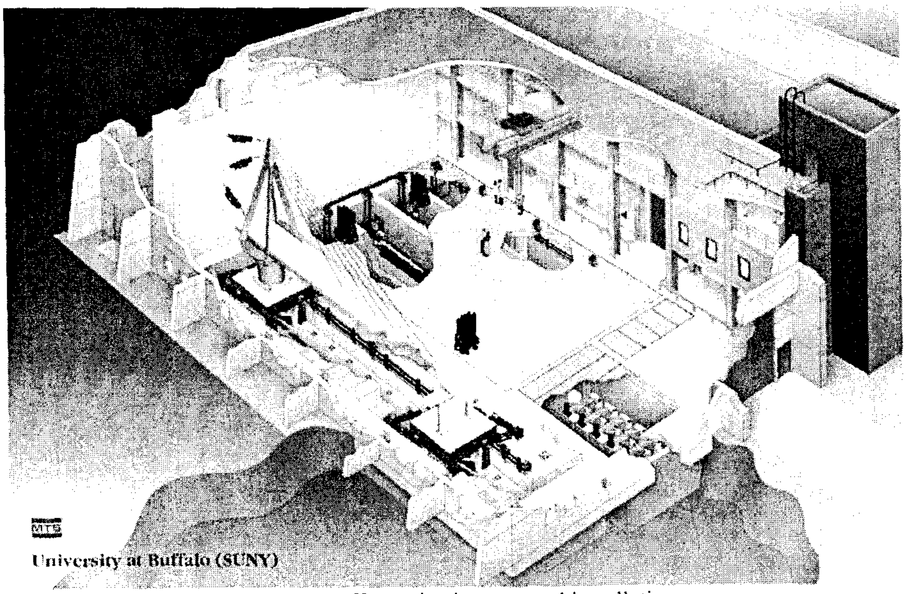

Figure 6: SUNY Buffalo seismic-structural installation

SUNY Buffalo uses two MTS 469D seismic controller for two 6-DOF shake tables and one STS structural controller for various servo-hydraulic actuators. All three controllers contain ScramNET PMC cards. Several other reflective memory nodes exist in various PC뭘for simulation, control and data-acquisition (Figure 7).

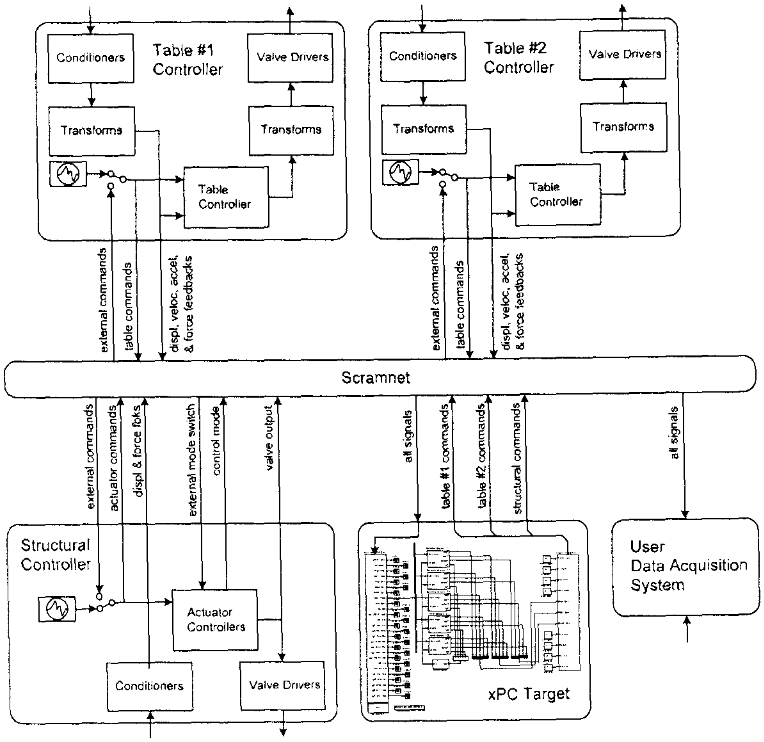

Figure 7: SUNY Buffalo ScramNET implementation diagram

A possible realtime hybrid test is shown in Figure 8 (Reinhorn, 2005). A 3 story building is tested with the first and third stories simulated on a PC, and the second story tested on the shake table. The shake table provides the first to second floor inter-story shears, while the external servo-hydraulic actuator provides the third to second floor inter-story shears. The simulation provides the commands to the system and updates the simulation with the feedbacks from the real system.

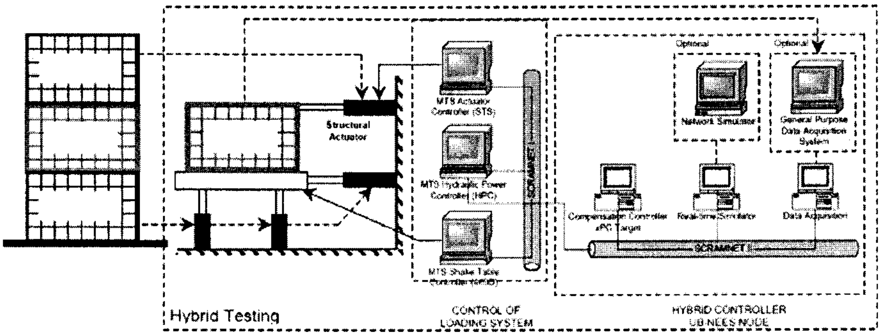

Figure 8: Example hybrid test

7. Conclusion

MTS has implemented a unique reflective memory architecture into its seismic and structural test systems. This architecture has allowed new and unique configurations of control and simulation to be implemented. The ScramNET fiber-optic reflective memory solution meets the demand for realtime deterministic control with minimal modifications to current control systems. The implementations have proven extremely successful, and has allowed the researcher infinite possibilities for new control and simulations.

8. References

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