Design Considerations for Stand-alone Haptic Interfaces Communicating via UDP Protocol

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Notice: The work described in this poster is also discussed in the paper "Design Considerations for Stand-alone Haptic Interfaces Communicating via UDP Protocol", in the WHC Proceedings.

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Overview

- This work was motivated by the need for high-speed communication between a stand-alone haptic interface and an external computer running haptic rendering algorithms.
- The results and observations from three modes of operation are contrasted with theoretical timing models in order to isolate potential problems and verify predicted models.

Hardware Platform

- The haptic interface (Ministick) is a point-contact joystick that couples three rotationally actuated five-bar loops to 3-DOF endpoint force and motion (see Fig. 1). The design is based on a unique fully-parallel, 10 rigid link, 12 revolute joint spatial architecture that affords the structural stiffness typically associated with parallel mechanisms, but with the range of motion approaching that of serial linkages. A custom embedded controller was constructed for the Ministick based on an 8-bit ATMEGA128 microcontroller and a 10 Mbps half-duplex Ethernet interface.
- Intense calculations involved in determining end effector position and motor torques take place on the remote computer. Low level position readings and motor torque commands are sent via UDP packets over Ethernet between the remote computer and embedded controller at the haptic update rate (Refer to Fig. 2).

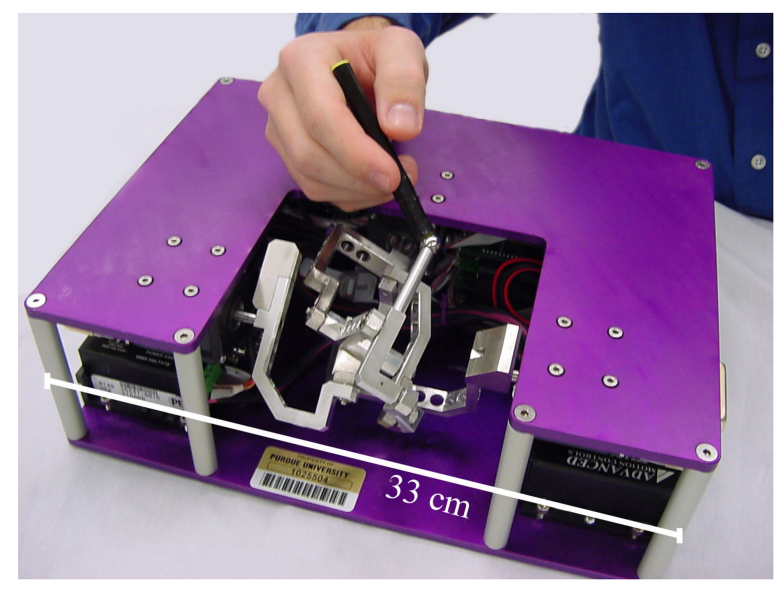

Fig.1: The 3-DOF Ministick

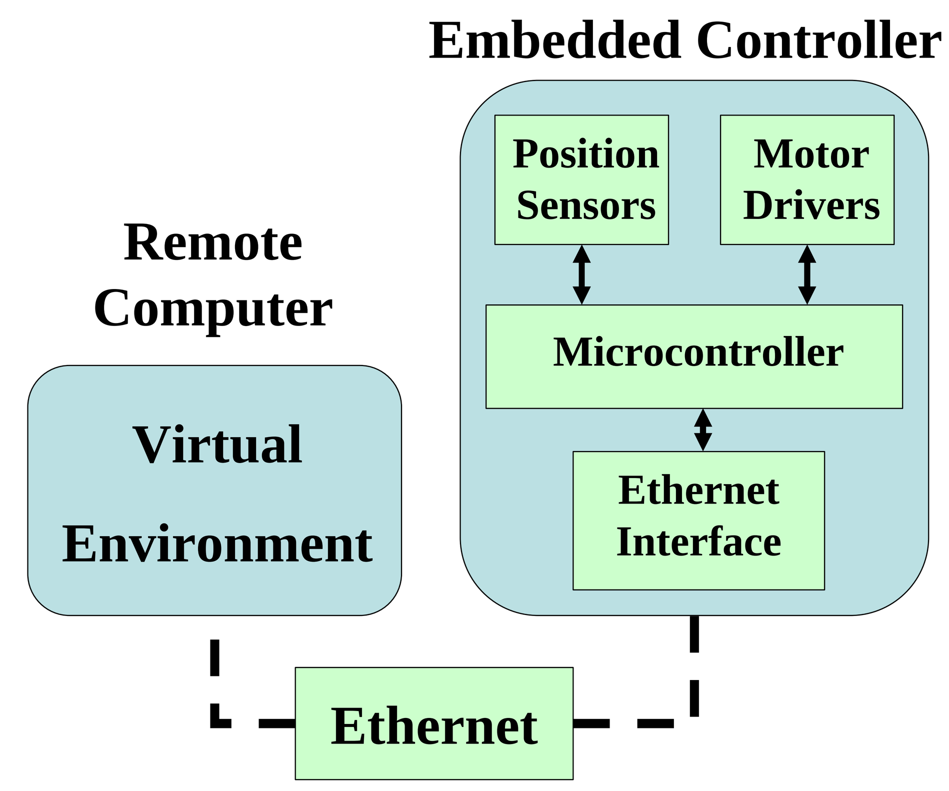

Fig.2: System diagram

Client Mode

- The embedded controller is programmed to wait until a motor torque command is received from the remote computer, process the command, then send a packet of position readings back to the remote computer.
- A theoretical maximum update rate of 1972 Hz is calculated from the computation times for the embedded controller (230 μs) and remote computer (155 μs) and UDP packet transmission round trip time (122 μs) (See Fig. 3). An update rate of ~3800 Hz is achieved, however, when the remote computer sends two initial motor torque command packets, which effectively doubles packet processing by both the remote computer and embedded controller (See Fig. 4).

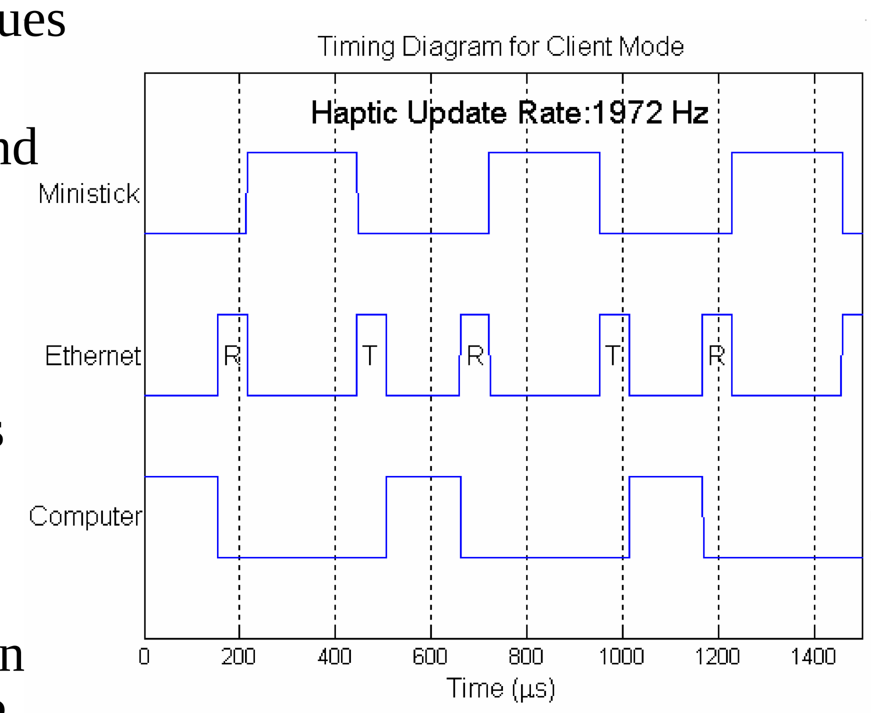

Fig.3: Timing diagram for client mode operation running at 1972 Hz

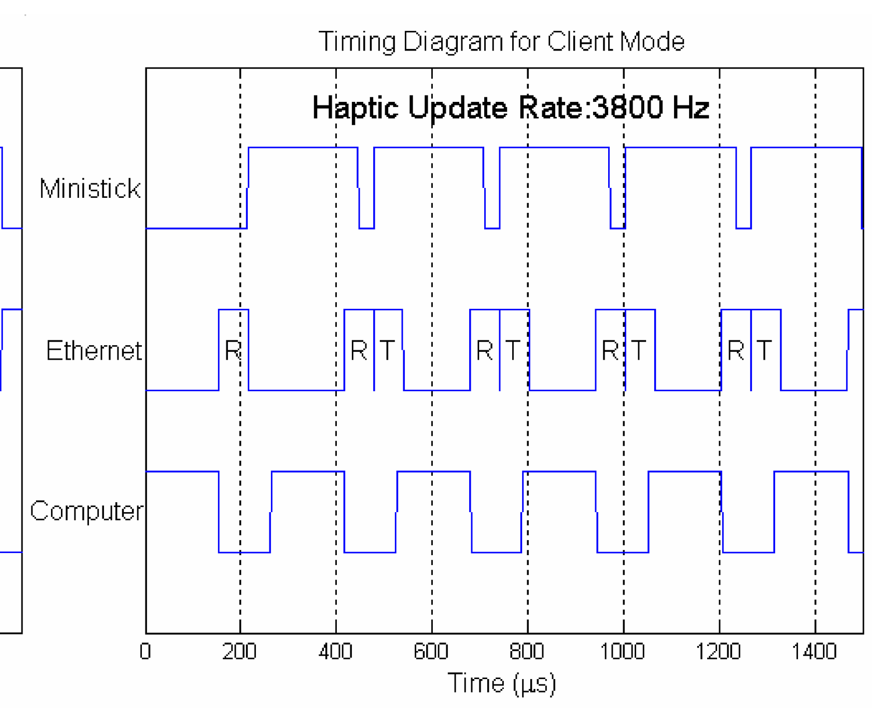

Fig.4: Timing diagram for client mode operation running at 3800 Hz

Server Mode

- The embedded controller is programmed to transmit position data packets at a fixed haptic update rate, then process the actuator command packets sent in response by the remote computer as they arrive.
- Timing diagrams for server mode operation running at 1972 Hz and 3800 Hz are shown in Figures 5 and 6 respectively. It was discovered that due to features specific to the Gigabit Ethernet standard, that when using a remote computer equipped with a Gigabit Ethernet controller, the server mode only operates as shown in the figures when the Ethernet driver's maximum interrupt rate is set at least twice the desired haptic update rate.

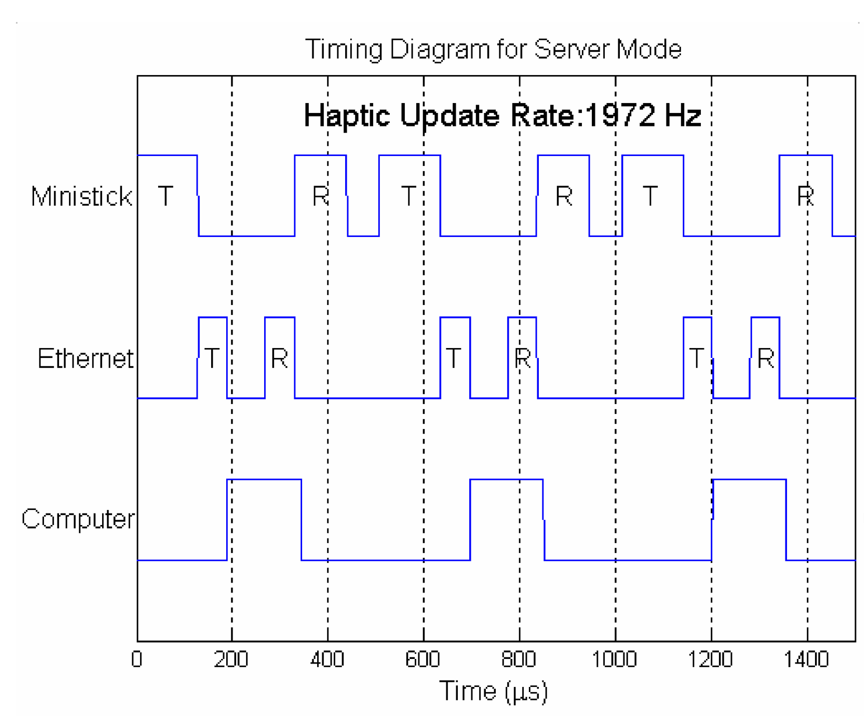

Fig.5: Timing diagram for server mode operation running at 1972 Hz

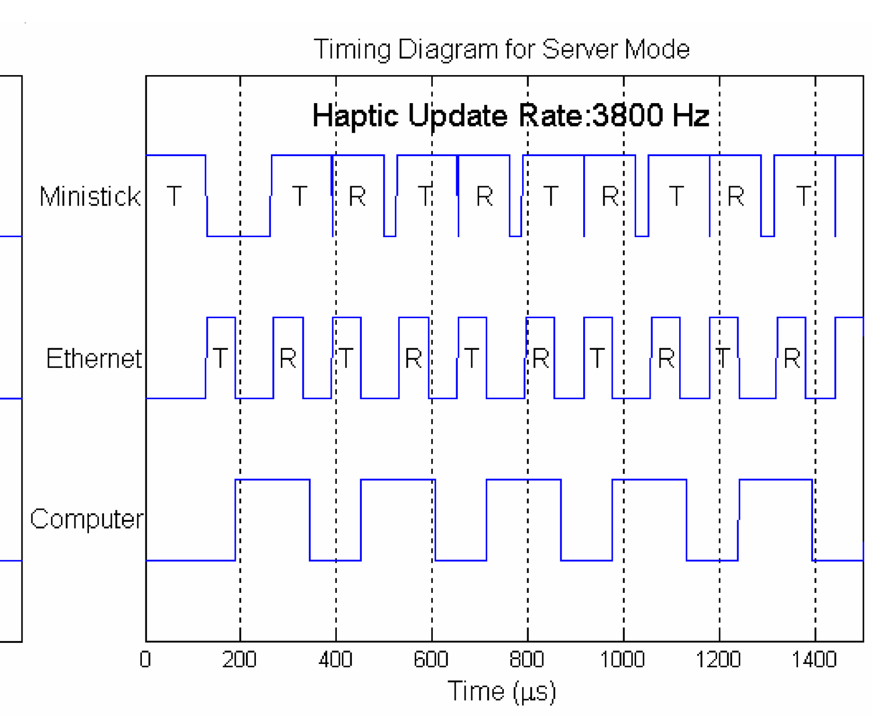

Fig.6: Timing diagram for server mode operation running at 3800 Hz

Distributed Mode

- It is feasible that a complicated virtual environment model could cause the remote computer to take longer than the 155 μs shown in the current timing diagrams. A novel way to alleviate this potential problem is to distribute the workload of processing the Ethernet packets among two or more remote computers (See Figures 7 and 8).

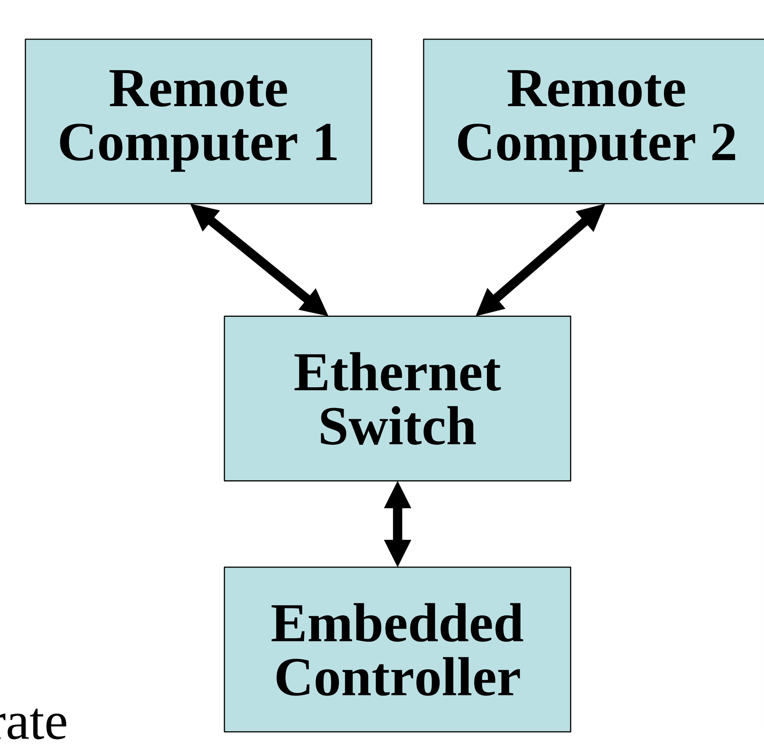

Fig.7: Configuration diagram for distributed mode operation

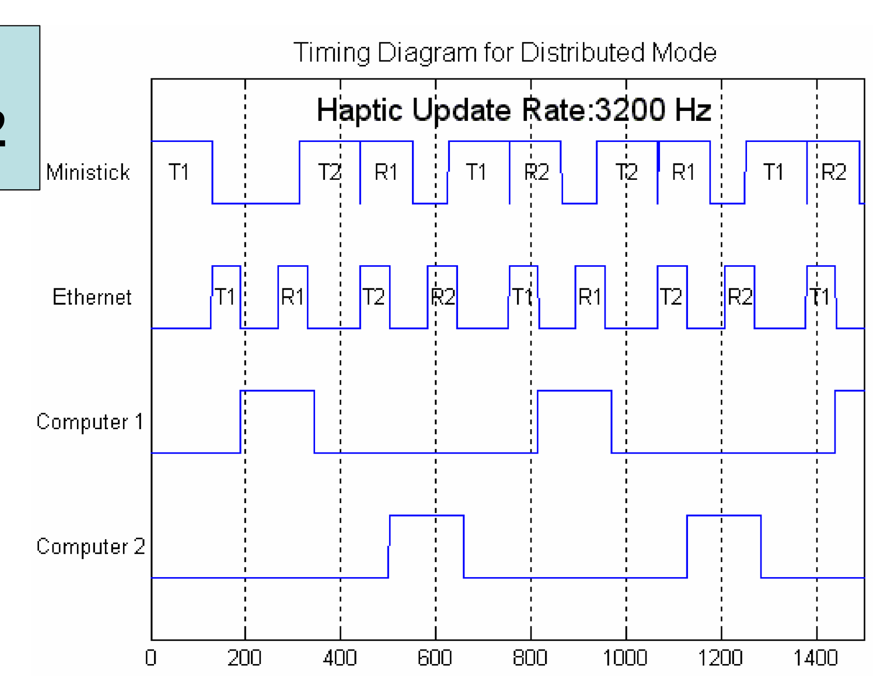

Fig.8: Timing diagram for distributed mode operation running at 3200Hz

Conclusion

- UDP protocol over Ethernet has been shown to be a viable method of communication between haptic interfaces and remote computers with update rates reaching 3800 Hz.
- The upper bound of 3800 Hz in our system was found to be dictated by the speed and efficiency of the embedded controller and is not a global bound for communication with haptic devices using UDP.
- Ways to modify the embedded controller to increase the maximum achievable update rate include using a faster microcontroller, a 100 Mbps Ethernet controller with full-duplex capabilities, and a more streamlined Ethernet stack in firmware.