RAW ETHERNET BASED HYBRID CONTROL SYSTEM FOR THE AUTOMATIC CONTROL OF SUSPENDED MASSES IN GRAVITATIONAL WAVES INTERFEROMETRIC DETECTORS

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Abstract

In this paper we examine the performance of the raw Ethernet protocol in deterministic, low-cost, real-time communication. Very few applications have been reported until now, and they focus on the use of the TCP and UDP protocols, which however add a sensible overhead to the communication and reduce the useful bandwidth. We show how low-level Ethernet access can be used for peer-to-peer, short distance communication, and how it allows the writing of applications requiring large bandwidth. We show some examples running on the Lynx real-time OS and on Linux, both in mixed and homogeneous environments. As an example of application of this technique, we describe the architecture of an hybrid Ethernet based real-time control system prototype we implemented in Napoli, discussing its characteristics and performances. Finally we discuss its application to the real- time control of a suspended mass of the mode cleaner of the 3m prototype optical interferometer for gravitational wave detection operational in Napoli.

INTRODUCTION

The requirement on the computing power of digital systems for mechanical and optical control are becoming very stringent, due to the increasing complexity of the techniques necessary for control signal generation. In fact, although these systems require sampling rates of the order of 10 kHz, the most important requirement is the computing power, so that special boards are being developed and tested in order to satisfy it [1]. This is mainly due to the increasing complexity of the control techniques (e.g. adaptive control, neural network control or optimization based control). A typical example is represented by the digital control of the seismic attenuators of gravitational waves interferometric detectors, which require a quite large computing power coupled with a relatively high sampling rate (10 kHz) [1] and small control bands (10 Hz). An example of highly nonlinear control systems is given by adaptive optics control systems, characterized by large control bands ($\approx$ 1 kHz) and a large number of control channels [2], [3].

To address the problem we propose an hybrid control system architecture based only on standard hardware and software, combining the advantages of hard real-time systems and the large computing power available on PC based systems through use of the Ethernet link [4]. In this paper we discuss the proposed architecture, its implementation and the results of the tests used for its validation. Finally we present an application to the real-time control of a suspended mass of the 3-meter prototype of interferometric detector of gravitational waves (IDGW-3P), operational in Napoli [5].

CONTROL SYSTEM SPECIFICATION REQUIREMENTS

The digital control system sampling frequency, f_s, puts an upper limit to the Data Management Time, DMT, which can be defined as the time necessary to perform all the required sequential operations for the generation of the control signals. This time can be considered as the sum of two main times: the data transfer time, DTT and the data processing time, DPT. In particular, DTT is the time necessary for the internal data transfer, while DPT is the time necessary for processing the data and generate the output control signal. The relation between the DMT and f_s can formally be written:

$$DMT = DTT + DPT < \frac{1}{f_s} \ . \qquad (1)$$

Therefore, from the control theory the only real requirement concerning the generation of the control signals is that the data transfer and the computing are completed within the chosen sampling period.

TEST HARDWARE FOR CONTROL

On the basis of the above constraints, we developed a hybrid and general digital control system architecture that satisfies this condition. The system is composed by two sections, a standard real-time section (VME based) for system synchronization and a standard off-line section (PC based) for the computing, linked through a standard Ethernet network. In Fig. 1 the topology of the system is shown.

For the test configuration, part of the digital control system of the mode cleaner of the IDGW-3P is used as a real-time section. It is a VME based control system, constituted by a VME crate with a Thales VMPC6a with Gigabit Ethernet running LynxOS 3.1a interfaced through the VME with a 16 bit ADC-DAC from Pentland. This system is directly

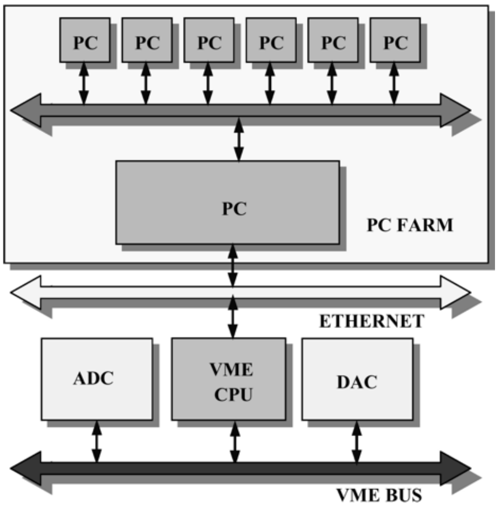

Figure 1: Hybrid control system architecture.

connected via Ethernet to our farm installed in Napoli, consisting of 8 APPRO 2114Xi with Pentium IV 2.4 GHz running Linux RedHat 7.3, kernel 2.4.20, with the OpenMosix extensions [6].

EXPERIMENTAL RESULTS

The evaluation of the upper limits of the hybrid control architecture requires the measurement of its DTT and DPT. In the next paragraphs we discuss the results of these two measurements on our test system. For the packet transfer we use the RAW Ethernet protocol, because it is lighter than the TCP/IP and UDP protocols, even if packet delivery is not guaranteed. This however is not a severe limitation, as long as the packet loss is kept within reasonable bounds, imposed by the band of the controlled system. We developed a simple “sanity checking” mechanism, by the use of a sequential marker attached to each sample sent. If the VME machine finds that the sequence number of a received packet is not correct, it can choose to ask the PC to resend it, or to go on.

Data Transfer Time measurement

The measurement consisted in the evaluation of the DTT necessary for data packets to be transferred from the real-time section to the PC farm and vice versa, through the point-to-point Ethernet link using the RAW Ethernet protocol. Each packet has an header 16 bytes long, containing various information: the address of the sender (6 bytes), the address of the receiver (6 bytes), the protocol number (2 bytes) and a packet sequence number (2 bytes). After this information the packet contains the control data to be exchanged between the two systems. The DDT was estimated as a function of the packet length and of the sampling frequency. The the transfer algorithm is composed of the following steps:

1. the real-time CPU waits for the trigger to convert the data;
2. the data pass from the ADC to the CPU through the VME;
3. the real-time CPU sends the data to the PC through Ethernet;
4. the PC performs the calculations;
5. the PC sends the output of the calculations to the VME through Ethernet;
6. the real-time CPU sends the received data to the DAC through the VME;
7. go to step 1;

The time needed to pass from step 3 to step 6 was measured on the real-time system, which, as we shall see, is the most critical part of the hybrid architecture. The measures were done for different packet sizes, in particular we tested a transfer of 1, 2, 4, 8, 16 data items from one side to the other at three different sampling frequencies: 1, 2 and 5 kHz. Each data item is 2 bytes long, this means that a packet with 4 data items is 24 bytes long (16 bytes for the header and 8 for the effective data). The measure was performed by acquiring data over a period of two minutes.

In Fig. 2 the fraction of sent packets that exceeds the maximum allowed transfer time for different packet sizes at different sampling frequencies is shown. The maximum allowed transfer time is given by the sampling period. The results show that the fraction of lost packets does not strongly depend from the length of the packet, but only from the sampling frequency. At 5 kHz the average loss is about 25%, at 2 kHz it is about 5%, while at 1 kHz it is about 0.3%. When packet loss is too high, we could decide to apply the resending of missing data.

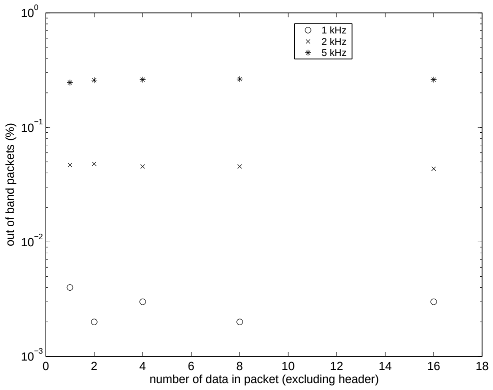

Figure 2: Fraction of packets that exceeds the maximum allowed transfer time for different data item sizes at different sampling frequencies.

We also evaluated the empirical cumulative distribution functions (cdf) of the DTT. In Fig. 3 and Fig. 4 the cdfs for data items of length 1 and 16 bytes at different sampling frequencies are shown. The distributions are similar, and here too we see the strong dependence from the sampling frequencies. In all cases no significant dependence on the packet length can be observed. From these results, we can conclude that the "bottleneck" in the procedure is given by the speed of the real-time CPU, which could not be fast enough to acquire the data from the acquisition board and deliver it over the Ethernet. In fact, we obtained worst performances by simply substituting the VMPC6a with a slower VMPC4a. The dependence on packet length was the same, but the packet loss increased considerably.

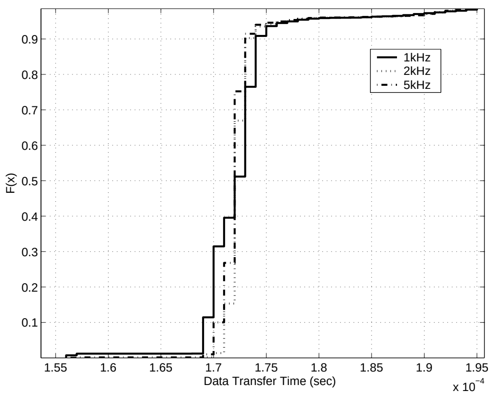

Figure 3: Cumulative distributions of the DTT for one data item at different sampling frequencies.

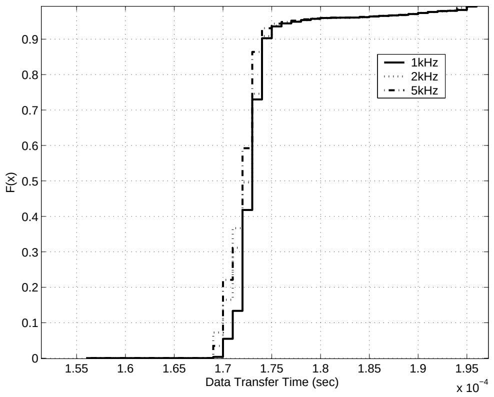

Figure 4: Cumulative distributions of the DTT for sixteen data items at different sampling frequencies.

Data Processing Time measurement

The computing power of our APPRO 2114Xi is 4 GFlop, measured with the Pallas Benchmark [7]. This means that if $f_s = 5$ kHz, then the theoretical maximum computing power available is at most 800 kFlop ($DTT = 0$). In our tests we used only the front-end machine of the farm. Of course, using all the PCs in the farm the computing power largely increases, but the global DTT must now include also internal DTTs of the farm Giga Ethernet link. Preliminary tests made with MPI[8] and Mosix[9] demonstrate that the global DTT practically doubles, but the available computing power becomes of the order the computing power of the whole farm.

Control of a suspended mass

As we said in the introduction, we tested the hybrid architecture in the control of a suspended mass of the Mode Cleaner of the IDGW-3P. More details about the system and the adopted control scheme can be found elsewhere[10]. In this test we use the same conditions, except for the sampling frequency, fixed at $f_s = 5$ kHz. The new architecture perfectly replaces the previous one, without any detected problem. The basic scheme of the control system implemented in connection with the mechanics of the system is shown in Fig. 5.

CONCLUSIONS AND PERSPECTIVES

We developed a general hybrid digital control system for the control of mechanical and optical systems, demonstrating its effectiveness both theoretically and experimentally. The control system was used for a conservative test control of a suspended mass of the Mode Cleaner of the IDGW-3P, with $f_s = 2$ kHz, demonstrating that the new architecture perfectly replaces the standard one without problems. The limits of our prototype are in connection with the hardware used, in particular from the computing power of the VME CPU, so that we expect large improvements from its upgrade. We plan to test this architecture for the control of the new designed state-of-the-art IDGW-3P suspensions.

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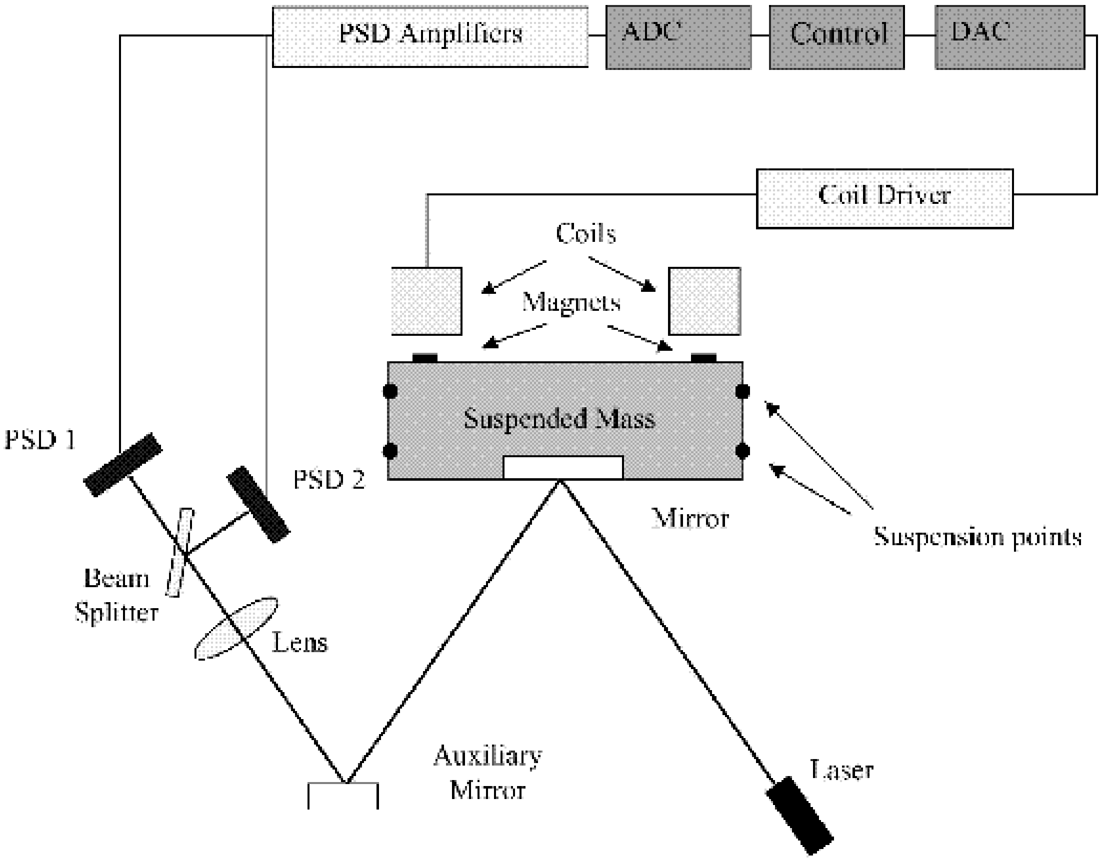

Figure 5: Control system of the suspended mass of the Mode Cleaner of the IDGW-3P.

[8] see for example http://www.mpi-softtech.com.

[9] see for example http://www.mosix.org and http://www.openmosix.org

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