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A CONFIGURABLE CONTROL SYSTEM FOR SMART STRUCTURE RESEARCH

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ABSTRACT

This paper describes a self-contained four-channel programmable controller designed to provide flexible sensing and control functions for situations requiring heavy computational load, real-time control, high-speed data acquisition, and fast signal processing. Based on a single-board Pentium computer, the SS10 incorporates eight channels of signal-conditioned input and four channels of controlled output. The input can be tailored to use a variety of sensing devices including strain gauges, piezoelectric ceramics, or other commercially available sensors. The outputs are controlled voltages that can range from –10 to +10Volts.

The range of possible applications is extensive thanks to the unit's easy re-programmability and the ability of the onboard computer to run a number of operating systems, including Linux, DOS, Windows, and RTOS. Depending on the algorithm programmed into the computer, the SS10 can be used for piezo servomechanism control, smart structure research, active vibration and shape control and analysis, and many other situations where fast analysis and short response times are essential.

The configurable controller is shown to offer a suitable platform for the successful implementation of control laws for inducing static deflection, resonant vibration, and active vibration control of a beam equipped with strain gauges, while subject to excitations from piezoceramic actuators.

INTRODUCTION

The SensorTech SS10 four-channel programmable controller provides inputs for up to eight strain gauges and four variable low-voltage outputs that can be programmed to respond to the input signals. The system comprises a single-board computer powered by an Intel CPU with up to 64 MB RAM, high-speed analogue to digital and digital to analogue converters, and an eight-channel strain gauge amplifier board. The system is integrated into a sturdy steel case that also houses the necessary power supplies.

Connections to the strain gauge amplifiers are made through eight five-pin self-locking connectors on the front panel, and the outputs are available though four BNC connectors, also mounted on the front panel.

The rear panel supports the 110VAC switched and fused power input, and various connectors for the on-board computer. These include an RJ45 Ethernet connector, a VGA monitor output, a nine-pin RS232/RS485 connector, and mouse and keyboard connectors.

The main function of the SS10 system focuses on the heavy computing application of real-time signal processing and control. A powerful Intel CPU (up to 266M Hz), large volume RAM (up to 64 MB), high-speed analogue-to-digital (60kS/s) and digital-to-analogue (9kS/s) converters, and highly efficient C or C++ code make it easy to develop and realize various real-time complex algorithms. These features also make it suitable for research and development projects in universities and for industrial control.

SPECIFICATIONS

The SS10 is designed to be used as a standalone controller or to be controlled by a host computer using RS232 or Ethernet communications. For standalone operation, the control algorithm resides in the memory of the onboard computer.

Input

Eight input channels are provided for use with half-bridge or full-bridge strain gauges. The default strain gauge resistance is 350Ohms. A trim pot is provided to allow precise adjustment of the bridge.

The gain of the strain gauge amplifier can be adjusted from 1000x to 2000x. The strain gauge amplifier also incorporates a low-pass filter set to 100Hz.

Output

The four output channels are capable of providing ±10 Volts peak-to-peak. These outputs also incorporate a low-pass filter set to 100Hz at –3dB point.

Communication Interface

Two methods of communication with external computers are provided: a serial communication interface based on RS232/485 protocol and a high-performance 100Base-

TX Ethernet connection that conforms to IEEE 802. For direct control of the operation of the onboard computer, mouse and keyboard sockets are provided.

Digital Signal Processing

Digital signal processing is provided by the onboard CPU, which is an Intel Pentium with 32MB RAM, expandable to 64MB. The operating system is embedded Linux. There is also a 24MB solid-state flash memory, which is used for hard disk emulation.

Development Tools

The following are used to develop and transmit new algorithms to the SS10:

- Desktop computer with Ethernet interface.
- Red Hat Linux 6.2 Operation System (provided on CDROM).
- Program Language: C and C++ (Integrated in Red Hat Linux Operation System).

EXPERIMENTAL RESULTS

The Sensor Technology platform is used in what follows to implement a controller that very effectively suppresses vibration from a beam. The form of the beam is shown in Figure 1. The beam has PZT patches and strain gauges attached to it and is treated as an Euler-Bernoulli beam [1]. The vibration suppression uses a Direct Strain Rate Feedback (DSRF) controller, which guarantees the stability of the overall system [2-3]. The control system also incorporates a hysteresis compensator that is based on an inverse Preisach model [4]. The hysteresis compensator is used in order to offset the nonlinearities in the PZT actuators being used. The combined hysteresis compensator/PZT actuator exhibits linear behavior [4]. The overall controller is shown in Figure 2. The reference strain signal $r(l,t)$ is set to zero if vibration suppression is pursued. If static deflection of the beam is needed then the reference strain signal $r(l,t)$ is set to a desired position. The saturation block in Figure 2 is used in order to ensure that the control voltage is within the allowable range for safely using the PZT patches.

A schematic of the platform used to implement in real-time the control strategy and the beam is shown in Figure 3. The system consists of a cantilever aluminum beam, an SS10 programmable controller, and amplifiers used to drive the PZT patches. The physical characteristics of the aluminum beam are listed in Table 1. One composite PZT patch and one strain gauge are bonded to each side of the aluminum beam. Each composite patch consists of four adjacent patches each having dimensions of 20 x 20mm^2. These are arranged in a square pattern with negligible gap between and are electrically connected in parallel. For modeling purposes each composite patch can be treated as a single patch of total area 40 x 40mm^2.

When an electric voltage is fed to the two composite PZT patches, one expands and the other contracts. Thus, a bending moment is generated. The SS10 controller is used to process real-time signals from the strain gauges via a half bridge amplifier circuit. The powerful Intel CPU of the SS10 controller executes the vibration suppression algorithm and generates an analog control signal, which is fed to the amplifiers for vibration suppression.

Experimental modal analysis for the beam being used is also pursued for the first three modes. Table 2 compares the experimental and theoretical natural frequencies. The theoretical values are based on the Euler-Bernoulli beam assumption. The agreement between experimental results and theoretical results is good. The damping ratios for the first three modes are also experimentally estimated through the half power point method [5] (see Table 2).

Once the nonlinear hysteresis in the PZT is eliminated through the inverse Preisach model, the PZT patches are considered as "linear actuators". A linear time-invariant (LTI) approach can then be used to analyze the overall control system. Figure 4 shows the frequency responses based on experimental modal analysis when the structure is subject to DSRF control and when the system is operated in open-loop mode. The DSRF controller clearly adds substantial damping over a wide bandwidth. The vibration of the cantilever beam is therefore expected to be largely suppressed, especially, when the exciting frequency is close to a natural frequency.

Experimental implementation of hysteresis compensation and DSRF control for vibration suppression was done on the SS10 platform. It is shown in Figure 5 that when an external signal is applied to the cantilever beam very effective vibration suppression can be obtained through DSRF control (see Figures 5b-5c). The system that does not incorporate the DSRF controller exhibits much longer vibration (Figure 5a).

Table 1. Physical Parameters of the Aluminum Beam

Young's Modulus (GPa) E	Area Moment of Inertia (m^4) I	Density (Kg/m^3) ρ	Thickness (mm) t	Width (mm) b	Length (mm) L
72	1.81×10^{-11}	2700	1.62	51	476.5

Table 2. Experimental Estimation of the Beam's Natural Frequencies and Damping Ratios

Mode	Natural Frequency (Hz)		Estimated Damping Ratio
	Theoretical	Experimental	
1	6.0	6.2	0.028
2	37.3	38	0.037
3	104.5	106	0.127

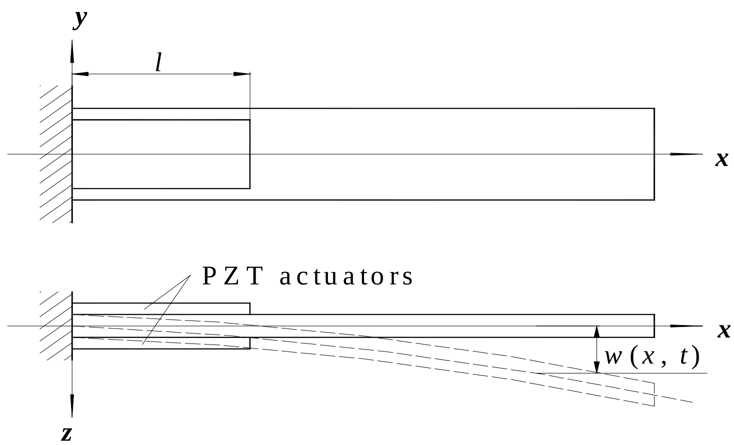

Figure 1. Geometry of a cantilever beam bonded with PZT actuators.

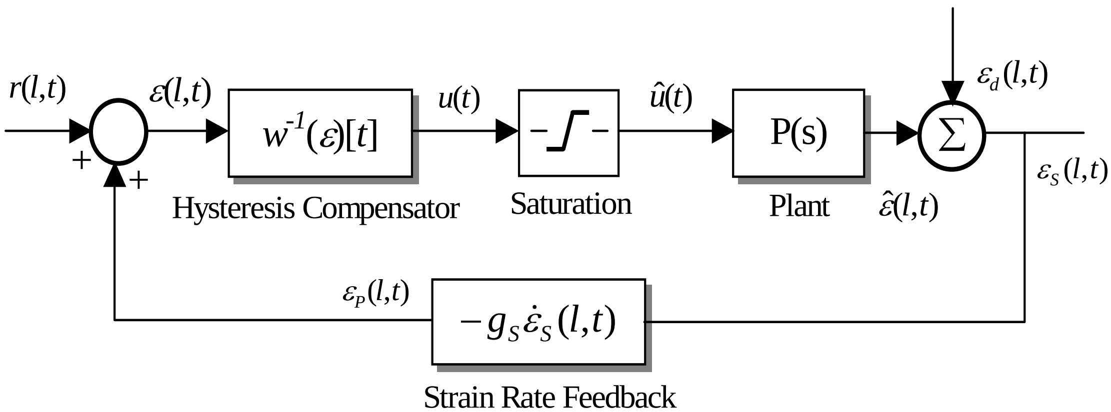

Figure 2. Block Diagram of the Feedback control System.

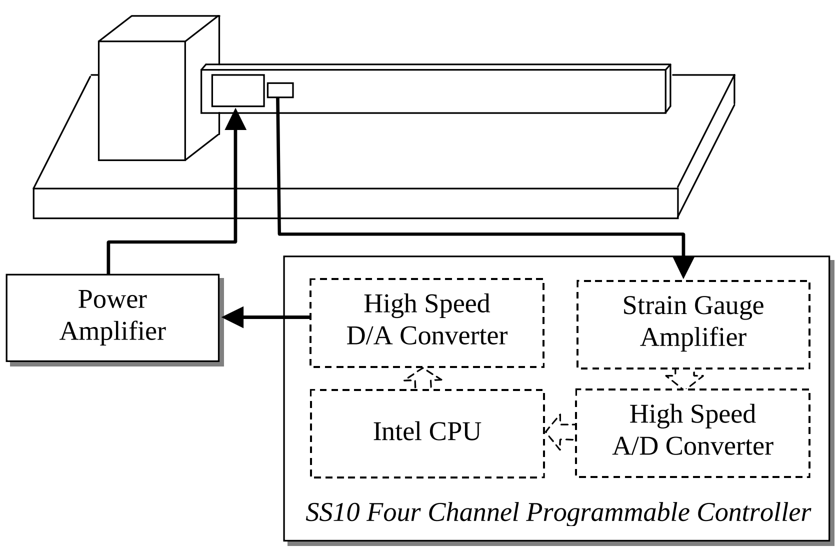

Figure 3. Experimental Rig.

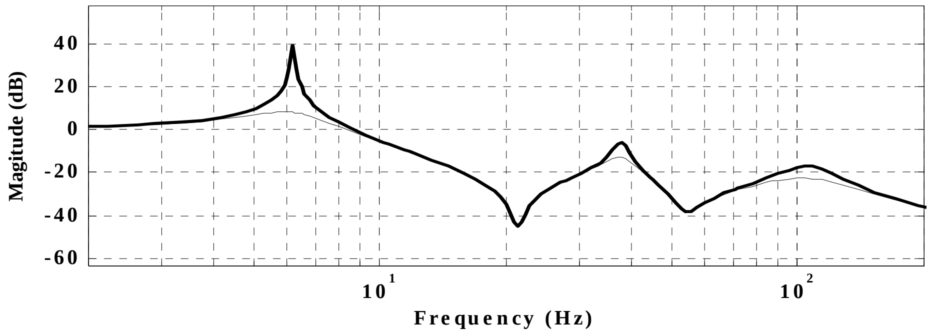

Figure 4. Frequency Response Functions: ----- open loop; — DSRF control.

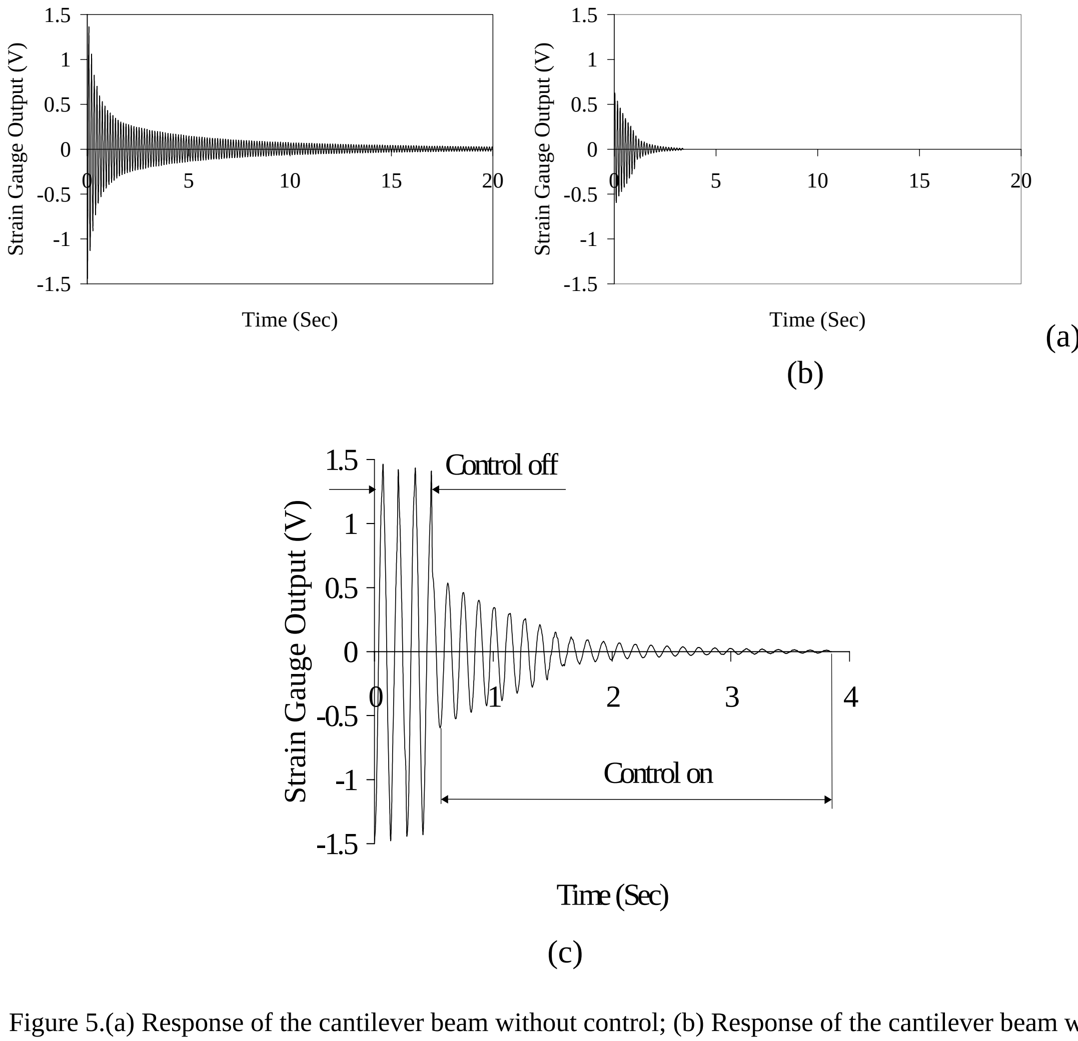

Figure 5.(a) Response of the cantilever beam without control; (b) Response of the cantilever beam when subject to DSRF control; (c) Response of the cantilever beam with DSRF control initially off and then turned-on.

CONCLUSIONS

A controllable programmer has been developed that allows sensing and control of shape and vibration through the use of a variety of sensors and actuators. The system is self-contained and can be programmed using a wide range of software languages and hardware interfaces. Its features make it suitable for research and development projects in universities and for industrial control.

REFERENCES

[1] C. Mei, B.R. Mace and R.W. Jones 2001, Journal of Sound and Vibration 247(5), 765-784. Hybrid Wave/Mode Active Vibration Control.

[2] C.L. Robert, S.R. William and G.P. Gary 1998 Adaptive Structures Dynamics and Control. NY: A Wiley-Interscience Publication.

[3] P. Andre 1997 Vibration Control of Active Structures. Dordrecht: Kluwer Academic Publishers.

[4] H. Hu and R. Ben Mrad 2002 Journal of Mechanical Systems and Signal Processing, in review. A Discrete Compensation Algorithm of Hysteresis in Piezoceramic Actuators.

[5] S.S. Rao 1995 Mechanical Vibration. Massachusetts: Addison-Wesley .