A TMS320C50-Based Algorithm Control

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ESIEE, Paris

September 1996
SPRA329

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Contents

Figures

A TMS320C50-Based Algorithm Control

Abstract

Active structures, used for manufacture satellites, robots or others industrial processes, are subjected to external disturbances inducing oscillation of the structure. With the technical progress of the last few years, piezoelectric sensors and actuators are now used to control such structures. The aim of our research is to develop a control algorithm embedded on a DSP board in order to stabilize a plate covered with two piezoelectric layers and subjected to an external disturbance.

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Introduction

Active structures, used for making satellites, robots or other industrial processes, are subjected to external disturbances inducing oscillation of the structure. With the technical progress of the last years, piezoelectric sensors and actuators are now used to control such structures.

The aim of our study is to develop a control algorithm embedded on a DSP board in order to stabilize an embedded plate covered with two piezoelectric layers and subjected to an external disturbance. This plate, presented below, is a model of an active structure:

First, a parameter identification of the structure has been realized. We choose an ARMAX model that means the process is Auto-Regressive and Moving Average with eXternal input. This model is used to represent the effects of the control and disturbances on the output. So, we defined the state space representation of the system in order to apply some control algorithms [5].

Then, with the software Matlab/Simulink, we realize a simulation scheme of a control by optimal state feedback with the discrete time Kalman observer. The quadratic cost criterion associated with the optimal regulator is $J = \sum x^T Qx + u^T Ru$. The closed loop system obtained by the use of the optimal control minimizes the cost criterion.

Finally, we proceed to the implementation on the DSP, TMS320C50 [11], of the control algorithm in order to make real-time applications. This last point requires three steps:

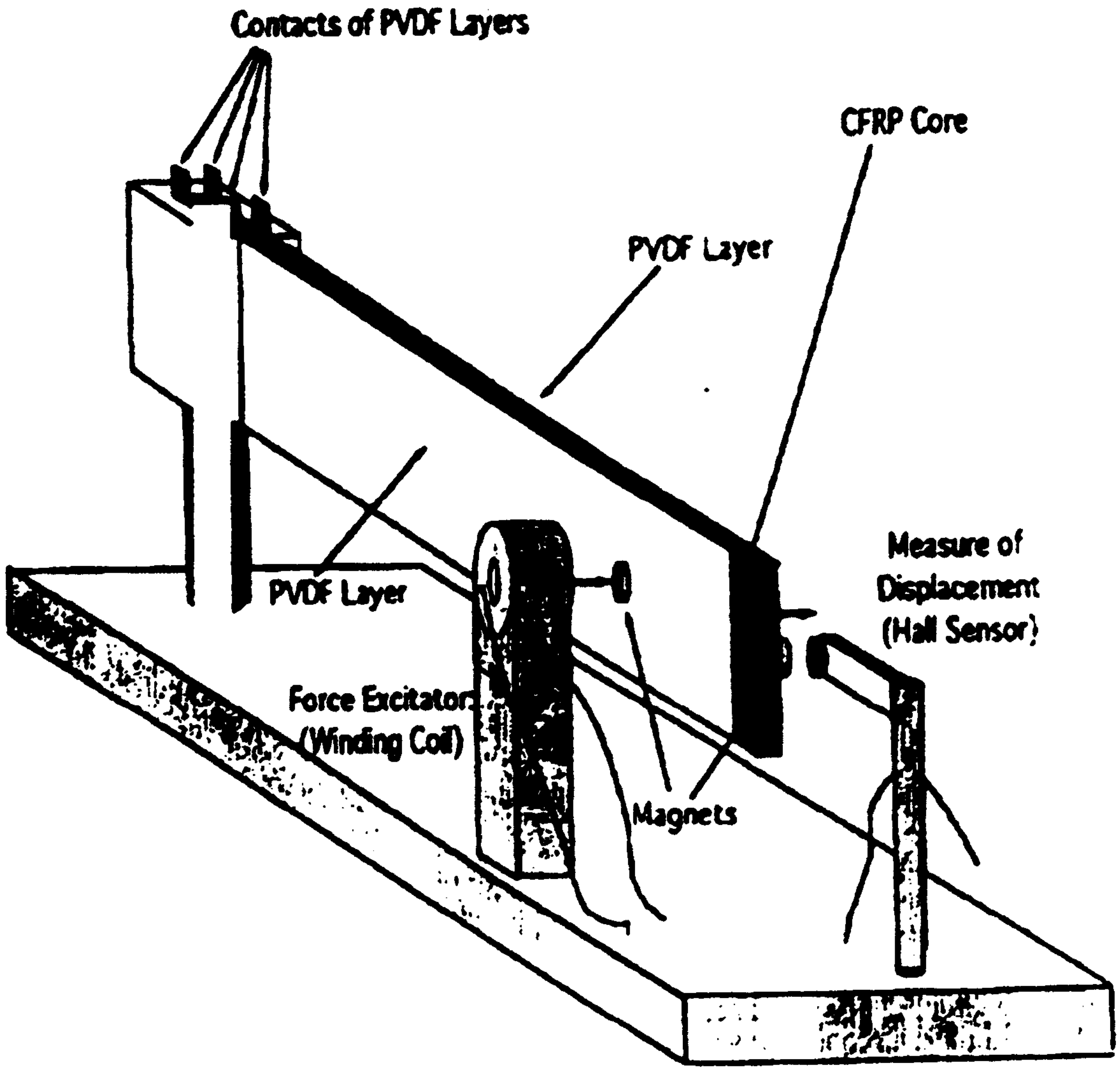
First, it’s necessary to create two block drivers (for the input and the output). The first one allows us to read data from the analog input and the second is used to control the system. These drivers are written in C with architecture of S-function that makes them readable in the Matlab environment. So, we can use these blocks in a Simulink scheme.

Using the Real Time Workshop toolbox from simulink, we generate the C code from the scheme created previously.

At last, after having written initialization programs for the TMS320C50 and for its analog interface, we create an executable file for the DSP with the optimizing C compiler from Texas Instruments [12].

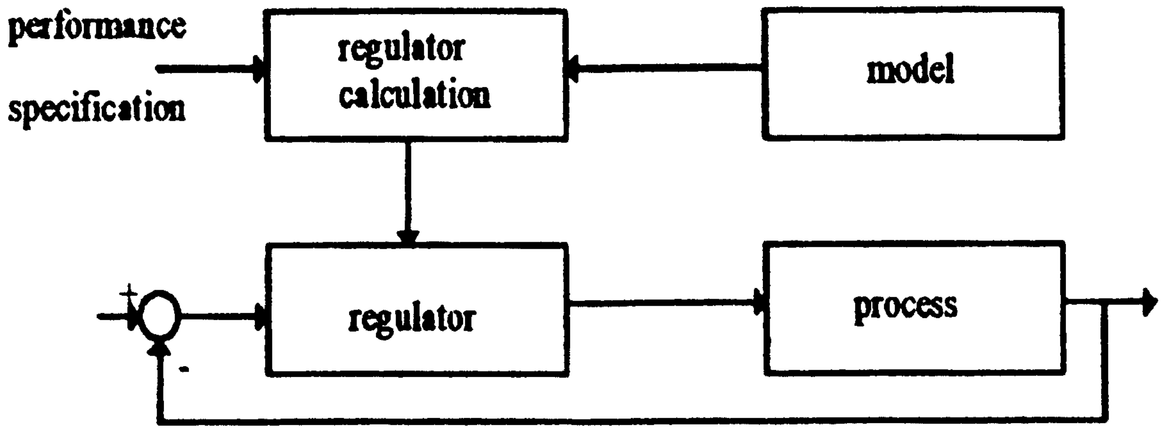
In a word, our study leads to the implementation on a DSP TMS320C50 of a control algorithm quite efficient (an optimal state feedback through the Kalman filter) with a precise determination of weighting matrices used for the optimal control.

Figure 1. Active Structure



Parameter Identification Specification

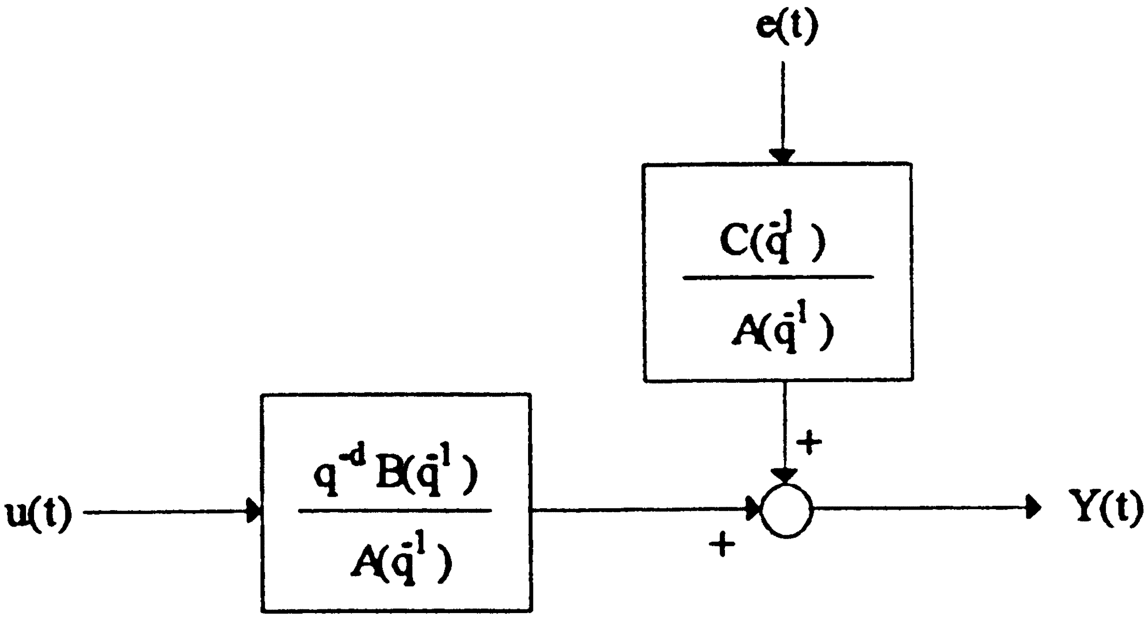
Figure 2. Regulator Calculation



The design of a regulator can be schematized of the next manner: The identification is going to allow us to determine the model of the process - piezoelectric plate and power amplifier - from input and output measures of the system. Thus it will be possible to implement a control algorithm from obtained model. The identification will be made using ARMAX model [5]. It concerns the model used to represent both the effect of the control and disturbances on the output of the system. ARMAX means that the system is auto-regressive and moving average with external input, that in the present case is u(t).

The Figure 3 represents the process modeled by ARMAX model.

Figure 3. ARMAX Model



Identification Results

The result of this identification gives us process and noise transfer functions as well as a graph allowing to visualize the real output and the predicted output with the prediction error of model.

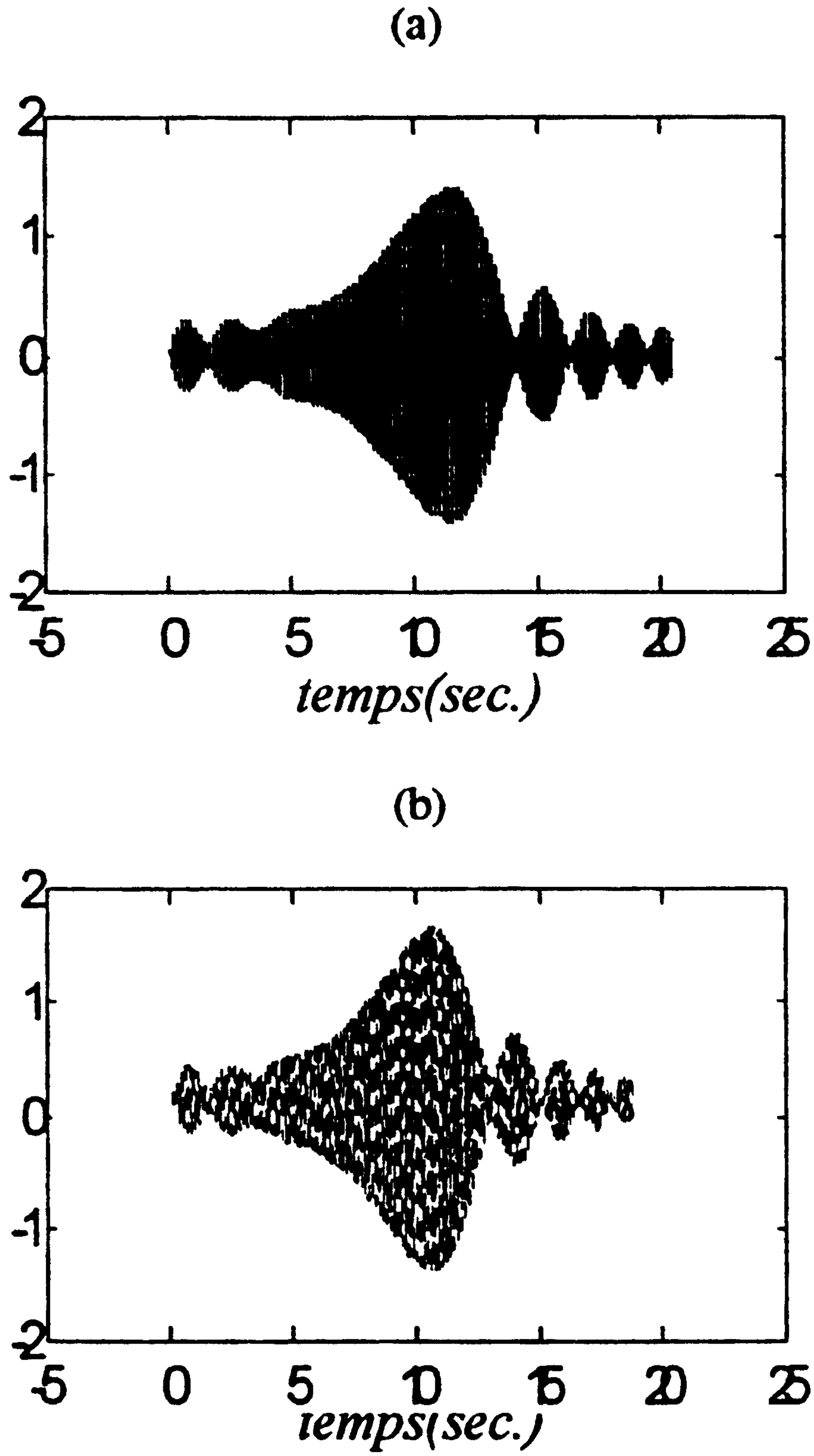
The identification results give:

$$TRANSFER-FUNCTION = \frac{-0.004664z^2 + 0.009241z}{z^2 - 1.845z + 0.9934} \quad (1)$$

$$NOISE-MODEL = \frac{z^2 - 1.41z + 0.8089}{z^2 - 1.845z + 0.9934} \quad (2)$$

The Figure 4 below gives a comparison between the real output of the system and the output predicted by ARMAX model.

Figure 4. Output Measurement (a)/Model (b)



Control Simulation

Control through Kalman Observer

The Kalman observer is a Kalman filter [10] that allows to predict the state $\hat{x}(k)$ in noise presence. Once the observation matrix obtained (that we will call L in this case), it is possible to establish control laws thanks to the access to the state variables.

In the case of the piezoelectric plate control, we will be contented in a first time to calculate the stationary Kalman observer, and to establish law control with the former.

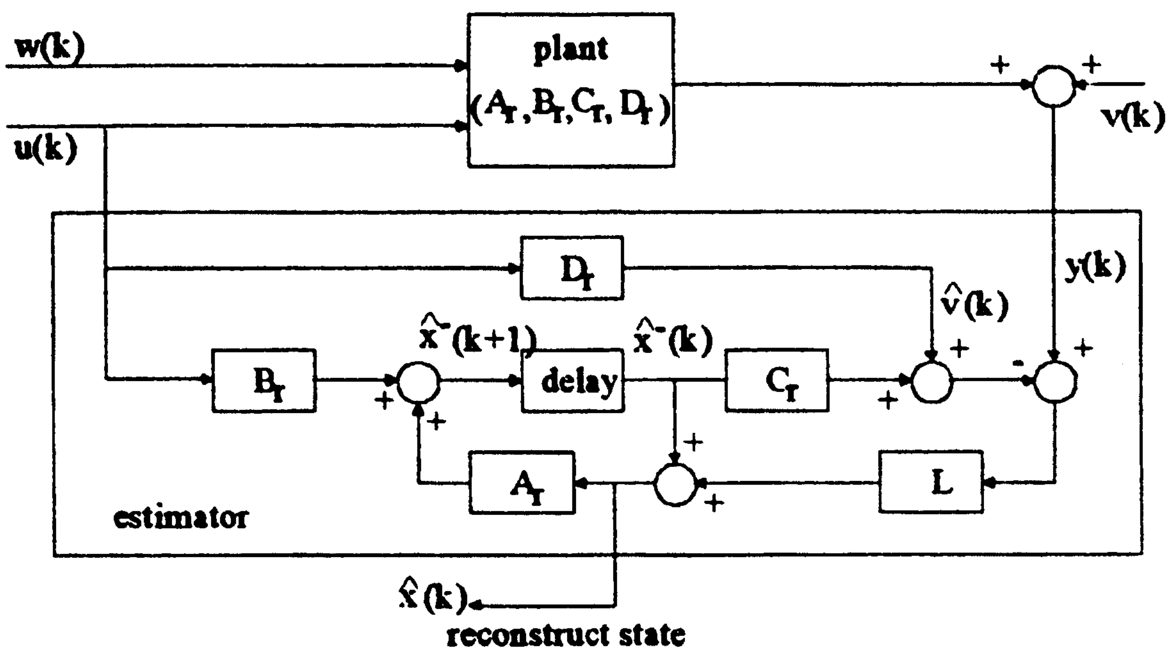
The observer by stationary Kalman filter is determined according to state equations (3) and (4). Its principle diagram is represented in Figure 5.

$$x(k+1) = A_r x(k) + B_r u(k) + w(k) \tag{3}$$

$$y(k) = C_r x(k) + D_r u(k) + v(k) \tag{4}$$

where *w* is the noise model and *v* the measurement noise.

Figure 5. Kalman Filter Block Diagram



This observer is such that:

$$\hat{x}(k) = \hat{x}^{-}(k) + L.(y(k) - \hat{y}(k)) \quad (5)$$

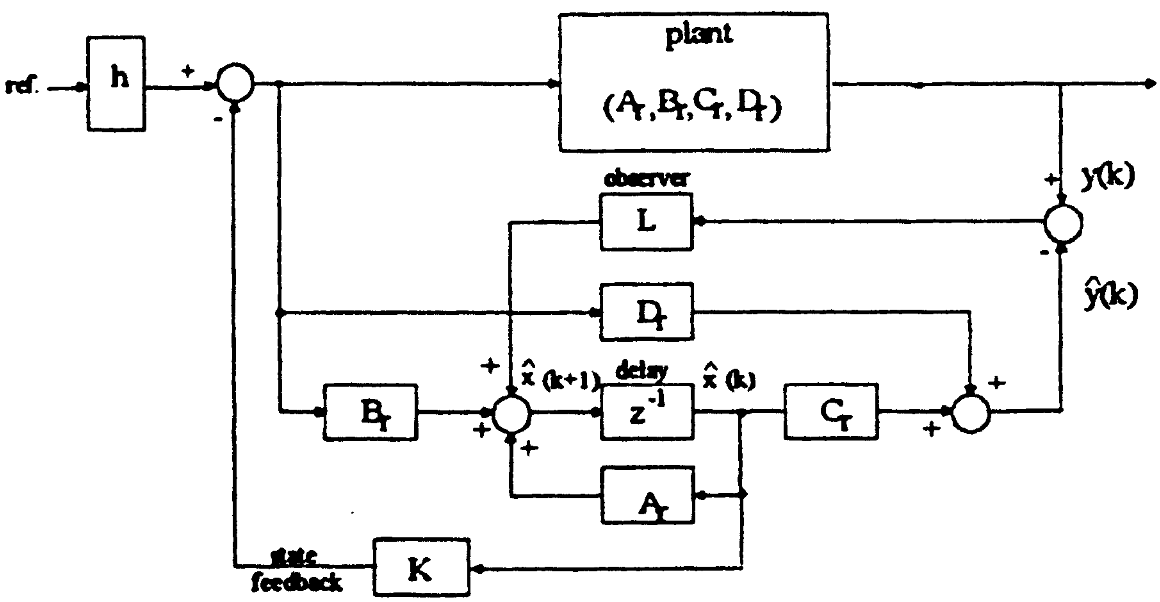
with

$$\hat{y}(k) = C_r.\hat{x}^{-}(k) + D_r u(k) \quad (6)$$

The gain matrix L is such that the stationary Kalman filter updates equations (5) and (6) so as to produce an optimal estimation of x.

When observer is calculated, one applies to the system the control by state feedback through the Kalman filter. In this case, it is possible to determine an optimal state feedback minimizing the cost function $J = \sum x^T Qx + u^T Ru$. This gain, noted K, is such that $u(k) = -Kx(k)$.

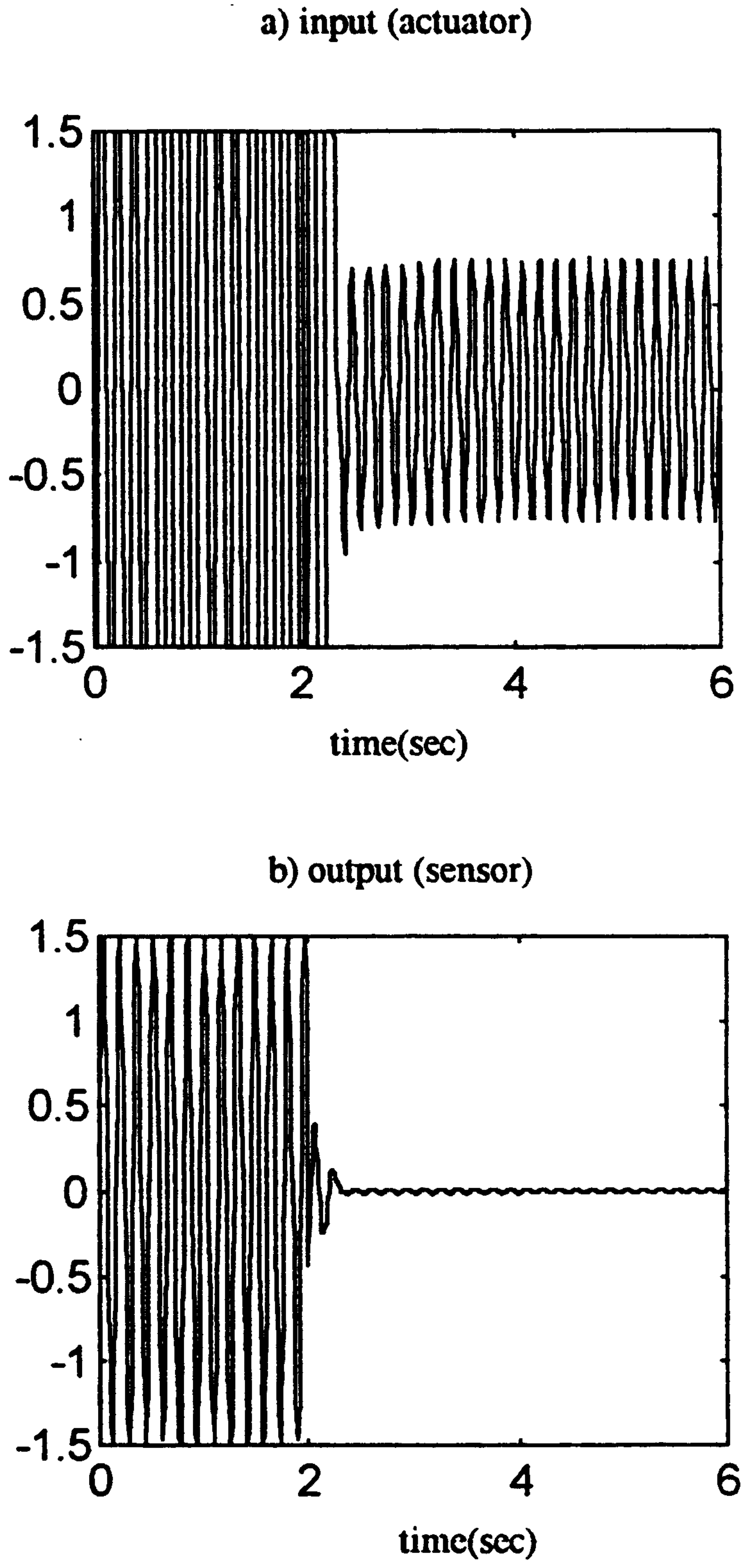
Figure 6. Control by State Feedback Through the Kalman Filter



Simulation Results

Extern disturbance is established before the control appears. It translated into oscillations of the plate. We activate the control two seconds later. The Figure 7 shows that the output stabilizes very rapidly.

Figure 7. Simulation of Control with Disturbance

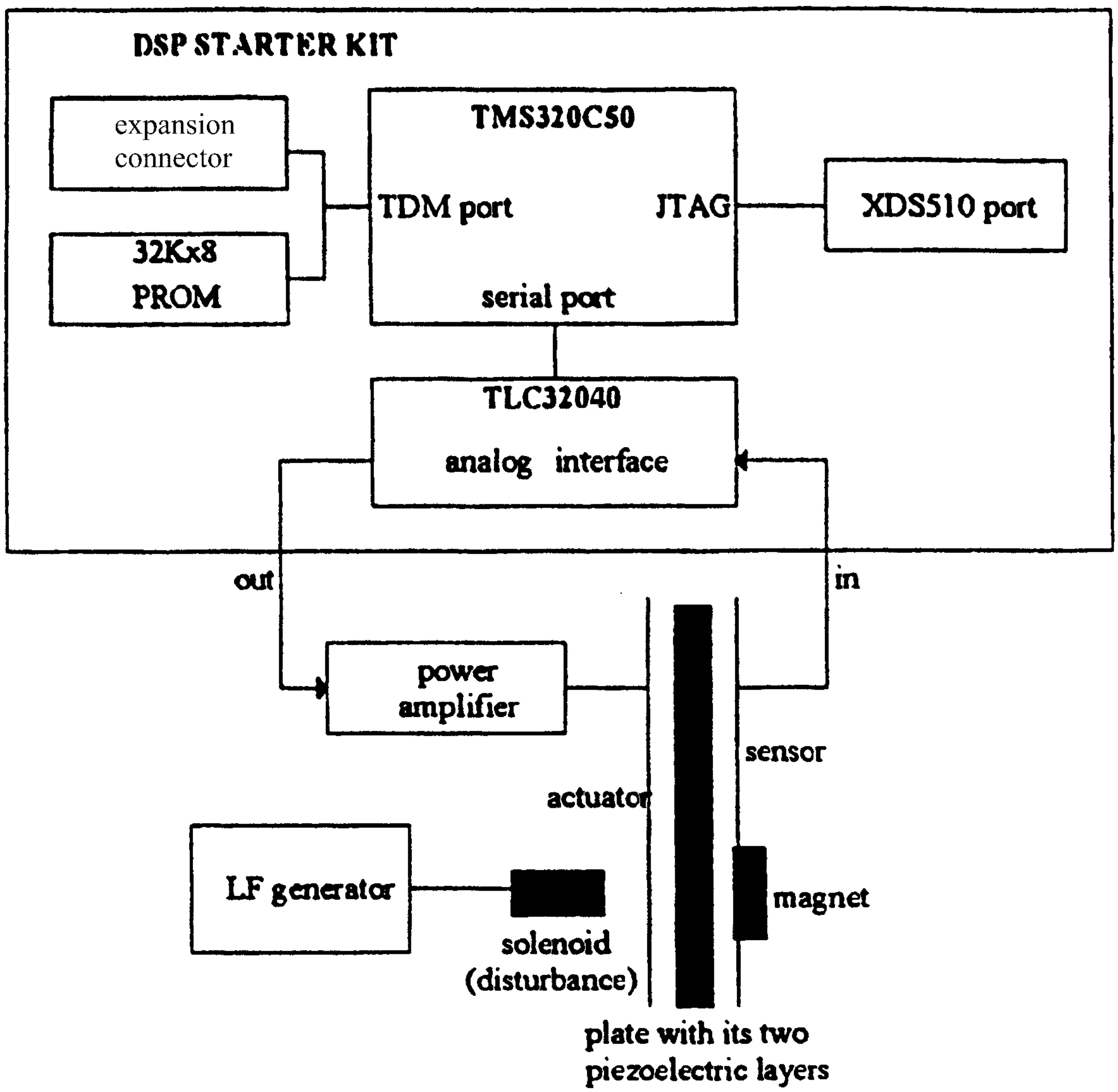


Real Time Implementation

Using DSP Card as Controller

Digital Signal Processors (DSPs) making digital control more practical. The special architecture and high performance of DSPs make it possible to implement a wide variety of digital control algorithms previously reserved for research work and simulation studies in laboratories. Thus it is that we use, here, a DSP as controller in this application.

Figure 8. Real Time Control of the Active Structure Plate



The solenoid generates an electromagnetic field that is going to create the disturbance in the form of oscillations of the plate. The DSP card allows to sample the signal by using the analog interface (TLC32040). The sampled signal is then processed by the TMS320C50 DSP, the calculated value is then sent to the system through the D/A converter and the power amplifier. Under the effect of this command, the plate will be then stabilized.

Implementation to DSP

The simulink software allows to create diagrams of simulation by using blocs having each their function: gain, sum, derivative, saturation, etc. By connecting these different blocs between them, one can therefore simulate control. This approach is very convivial for the user that can create its blocs what we will make to establish a direct link between simulink and DSP card. When one wants to use a control in real time by using simulink, it is necessary to create driver blocks under simulink allowing to make input/output access. It is necessary therefore to elaborate two blocs:

- the first for reading data from the A/D converter and the other for writing data on the D/A converter. Such a block is composed:
  - A S-function: it concerns a system function that is interlink with simulink during the simulation and that is linked to the generated code.
  - A C-Mex file: it is created from the S-function and as it is dynamically linked to matlab [13], it allows to place the s-function in a simulink diagram.
  - A Masked-bloc: the masked-bloc allows to define its proper dialogue box, the icon and initialization for the bloc. It is the direct representation of the S-function under simulink.

When these driver blocks are created, one inserts them in the control diagram under simulink. Then, one generates a C code by using the simulink real time workshop toolbox.

The C code is then compiled, assembled and linked with initialization files of the DSP card. Thus we obtain an executable file that we can load in the DSP so as to control the system in real time.

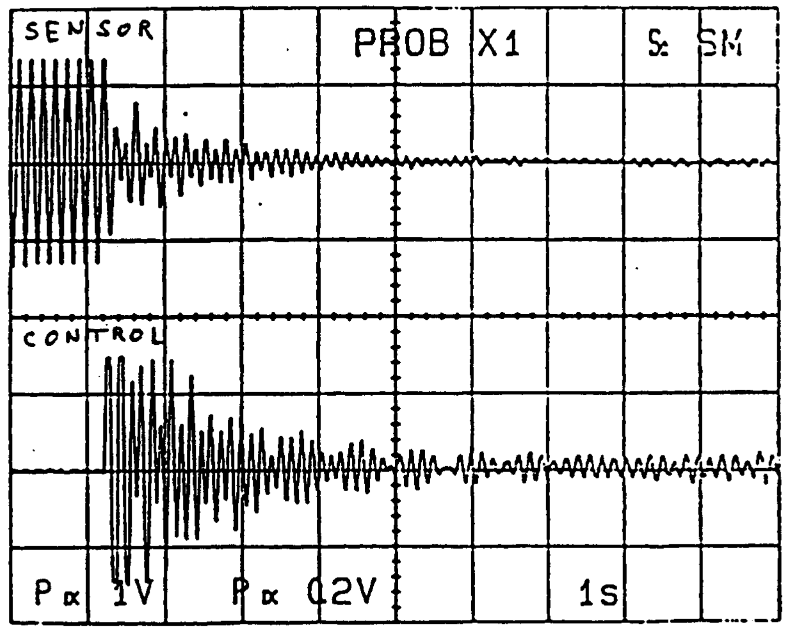
Real Time Test Results

We have applied the control by state feedback through the Kalman filter in two different cases:

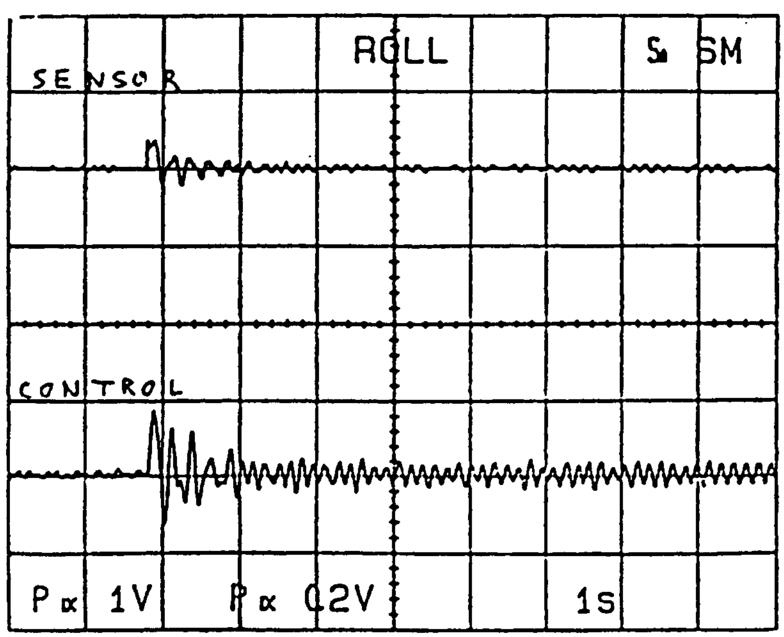
- firstly, we have executed the control while the external disturbance was already established, so as to verify that it can stabilize the plate rapidly under a strong disturbance (Figure 9a).
- then, we have tested it by loading a short disturbance in control presence to see what is the performance of this method in regulation (Figure 9b).

Figure 9. Real-Time Test with Disturbance

(a)



(b)



Conclusion

This paper has presented the precise design of a regulator for the control of active structure plates. The implemented method associates the Kalman filter like observer and an optimal state feedback. Performances and robustness of such a system are superior those of classic controllers. The implantation of this algorithm in a Digital Signal Processor, TMS320C50, has allowed to minimize calculation times and to increase the speed of convergence of the control.

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