A Smooth D/A-Converter for Robotic Applications

Johansson, Rolf; Zettergren, Einar

1988

Document Version:
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Johansson, R., & Zettergren, E. (1988). *A Smooth D/A-Converter for Robotic Applications*. (Technical Reports TFRT-7374). Department of Automatic Control, Lund Institute of Technology (LTH).

Total number of authors:
2

CODEN: LUTFD2/(TFRT-7374)/1-6/(1987)

A Smooth D/A-Converter for Robotic Applications

Rolf Johansson
Einar Zettergren

Department of Automatic Control
Lund Institute of Technology
January 1987

Department of Automatic Control **Lund Institute of Technology** P.O. Box 118 S-221 00 Lund Sweden	*Document name* Report *Date of issue* January 1987 *Document Number* CODEN: LUTFD2/(TFRT-7374)/1-6/(1987)
Author(s) Rolf Johansson and Einar Zettergren	*Supervisor* *Sponsoring organisation*

Title and subtitle

A Smooth D/A-Converter for Robotic Applications.

Abstract

The signal from a common D/A-converter is piecewise constant and the harmonics may cause problems in a sensitive system. Resonant objects with flexible structures are particularly vulnerable. This paper describes a way to decrease the amplitude of harmonic overtones. An interpolating D/A-converter with feedback is presented.

Key words

Resonance, Flexible structures, D/A-converter, Feedback, Digital control.

Classification system and/or index terms (if any)

Supplementary bibliographical information

ISSN and key title	*ISBN*

Language English	*Number of pages* 6	*Recipient's notes*
Security classification		

The report may be ordered from the Department of Automatic Control or borrowed through the University Library 2, Box 1010, S-221 03 Lund, Sweden, Telex: 33248 lubbis lund.

A SMOOTH D/A-CONVERTER FOR ROBOTIC APPLICATIONS

Rolf JOHANSSON *
Einar ZETTERGREN*

Keywords

Resonance, Flexible structures, D/A-converter, Feedback, Digital control

Abstract

The signal from a common D/A-converter is piecewise constant and the harmonics may cause problems in a sensitive system. Resonant objects with flexible structures are particularly vulnerable. This paper describes a way to decrease the amplitude of harmonic overtones. An interpolating D/A-converter with feedback is presented.

Introduction

The signal from a common D/A-converter is piecewise constant and the harmonics may cause problems in a sensitive system. Excitation of resonances in flexible structures may be undesirable in robotic and servo applications. Usually, a low pass filter would be used to make the output smoother. Another solution is presented in this paper and is based on interpolation between the sampling instants. It is known from Fourier series theory that the n:th harmonic of a square wave disappears in amplitude as $\frac{1}{n}$. The amplitudes of the n:th harmonics of a triangle wave disappear as $\frac{1}{n^2}$. The idea is therefore to compute the incremental control signal, to make D/A-conversion and then to make integration by analog techniques.

---

* Dept. of Automatic Control, Lund Institute of Technology, Box 118, S-221 00 LUND, Sweden.

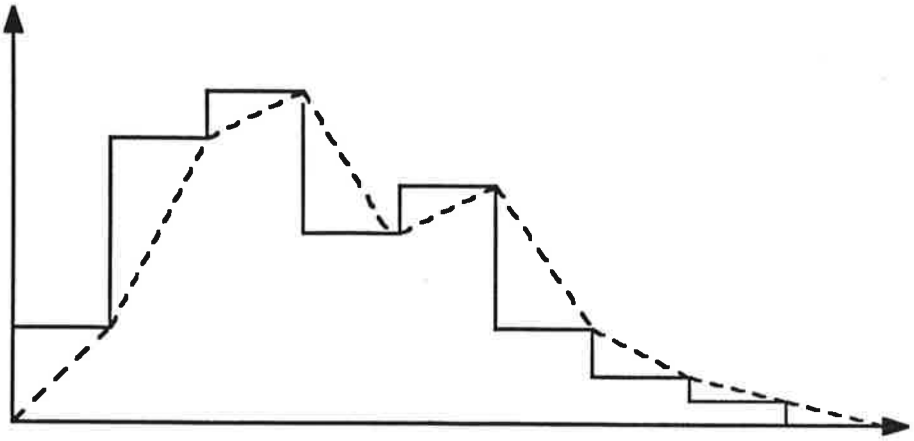

Figure 1. On-line interpolation of a stepwise constant signal.

An incremental regulator

A digital control signal u^* is often computed from the feedback signal y^* and command signal u_c^* according to digital control theory on the form

$$u^*(kh) = -r_1 u^*(kh-h) - s_0 y^*(kh) - s_1 y^*(kh-h) + t_0 u_c^*(kh) \tag{1}$$

where h denotes the sampling interval, see [1], and '*' denotes sampled data. An incremental regulator computes the incremental control signal rather than its absolute value. Let the difference operator be denoted by $\Delta = 1 - q^{-1}$ where q^{-1} is the backward shift operator. The incremental control Δu^* corresponding to (1) is easy to compute as

$$\Delta u^*(kh) = u^*(kh) - u^*(kh-h) =$$

$$= -r_1 \Delta u^*(kh-h) - s_0 y^*(kh) + (s_0 - s_1) y^*(kh-h) + s_1 y^*(kh-2h) + t_0 \Delta u_c^*(kh) \tag{2}$$

A standard solution is to store the absolute value of u^* in a register that is connected to the D/A-converter. The control signal is then updated with the increment Δu at each sampling interval.

Another D/A conversion method is now proposed as follows from figure 2. The basic idea is to integrate the D/A-converted control increments. The desired continuous control signal $u_{cont.}$ may then be obtained by integration of the discrete-time control signal Δu^* as

$$u_{cont.}(t) = u^*(kh) + \frac{1}{h}\int_{kh}^{t} \Delta u(\tau) d\tau \tag{3}$$

The feedback loop of the D/A converter is introduced as a necessary remedy to some inherent problems of integral action implemented by operational amplifiers, namely:

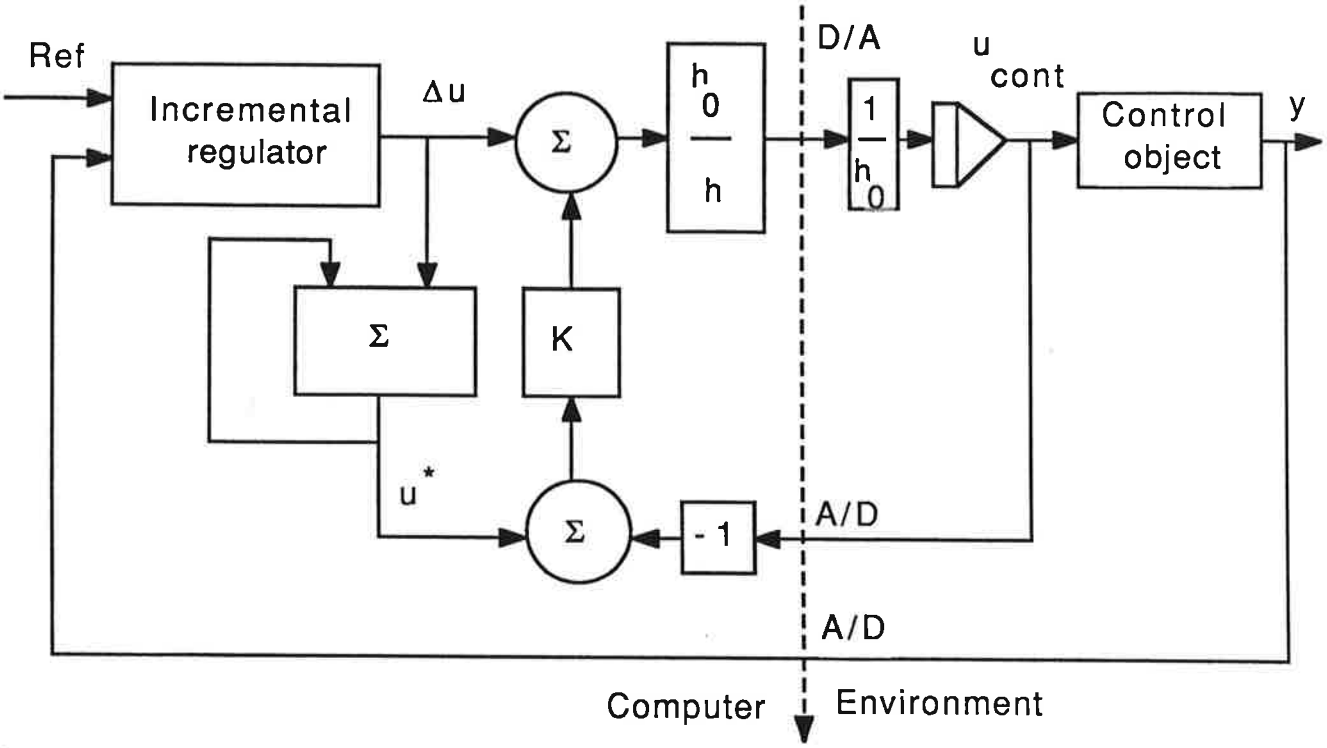

Figure 2. Block diagram of digital regulator and D/A converter

- The integrator is non-ideal
- Integrator drift

The control input u_{cont} is compared with the discrete-time desired control signal u^*. Feedback of the difference $u^* - u_{cont.}$ with a proportional feedback coefficient K assures that the discrepancy is very small. The benefit compared to traditional D/A conversion is in the smooth interpolating action, see figure 1.

Implementation

The above D/A-converter with feedback has been implemented with a standard D/A-converter (Analog Devices RTL-800), see [2], and with a regulator coded in Modula-2 on an IBM-AT personal computer.

The choice of proportional feedback constant K would be $K = 1$ to obtain full compensating action in one sampling interval. However, experiments show that it prooves better to choose $K < 1$. The choice $K \approx 0.5$ is a good rule of thumb.

The coefficient h_0 is chosen to scale the signals so that the dynamic range of the integrator is properly used for the intended sampling frequencies and the desired system bandwidth of the closed-loop control system. An h_0 that is too small may give quantization problems and an h_0 that is too large may cause saturation problems.

The choice is not critical in servo applications and the dynamic range is large with respect to the sampling frequency. Once the bandwidth has been chosen it holds in most normal servo operating conditions that the control input rate of change $\Delta u^*/h$ is not very dependent on the choice of sampling frequency.

Application

The new D/A-converter has been applied successfully to some sensitive servo problems. One successful application was on a laboratory process with many resonant modes namely the "ball and beam"-process.

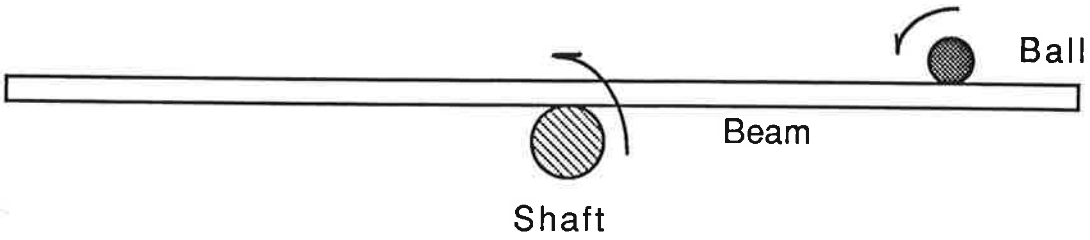

Figure 3. The ball and beam process

A DC servo motor is attached to the shaft and controls the angle of the beam. The ball balances on the beam and the control problem is the give the ball a given position. The beam is flexible and resonant. Harmonics of the sampling frequency may therefore give undesired excitation of the resonant modes - especially for higher desired closed loop bandwidths. The control was made with PID-control implemented with a 100 Hz sampling frequency. The control performance was judged superior to that of control with standard D/A-conversion. A higher desired closed loop bandwidth meant a more noticable difference in performance.

Phase lag of the new D/A converter

Digital control has one systematic disadvantage compared to analog control implementations. It introduces a phase lag due to the sampling and hold circuits of the A/D-converter. A standard zero order hold circuit has the approximate transfer function

$$G(s) = \frac{1 - e^{-sh}}{s} \approx h(1 - \frac{sh}{2}) \tag{4}$$

with an associated phase shift

$$\varphi = argG(i\omega) \approx -\frac{\omega h}{2} \tag{5}$$

This phase shift is common to all digital feedback control systems with A/D-converters. The new D/A-converter with feedback has in its present implementation also a similar phase lag in the D/A-converter. The discrete time difference operator Δ corresponds to a the continuous-time transfer function $1 - e^{-sh}$ and the integrator is modeled as $1/s$. The D/A-converter has thus the same phase lag as an ordinary A/D-converter. The resulting phase shift of A/D- and D/A-conversions in the new control system may therefore be estimated to be twice that of a standard digital control system. The phase shift is however linear with respect to frequency.

Conclusions

A new D/A-converter has been proposed and implemented. The D/A-converter has prooved very good for digital feedback control in cases where the sensitivity to harmonics otherwise would have limited the bandwidth. The D/A-converter has the following valuable properties:

- The output is interpolating and harmonics of the sampling frequency are effectively eliminated
- It is easy to implement
- It is not sensitive to the choice of sampling frequency.
- The phase shift is linear with respect to frequency.

The drawback compared to standard digital control is the following:

- The phase shift is twice that of a standard D/A-converter.

References

[1] K.J.Åström and B. Wittenmark: *Computer controlled systems*, Prentice-Hall, 1984.

[2] *RTI-800/815 User's manual*, Analog Devices and International Business Machines Corporation, 1986