# *Using TMS320 Family DSPs in Motion Control Systems*

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# Using TMS320 Family DSPs in Motion Control Systems

## Abstract

This application report discusses the most important issues concerning the use of TMS320 DSP-based systems in motion control. Motion control systems using fixed and floating-point processors are compared. Typical applications and experimental results are presented for schemes employing all common types of electric motors - DC, induction, brushless, and step.

This document was part of the first European DSP Education and Research Conference that took place September 26 and 27, 1996 in Paris. For information on how TI encourages students from around the world to find innovative ways to use DSPs, see TI's World Wide Web site at www.ti.com.

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# Motion Control

Motion control deals with the use of high performance electric motors and is a very important part of industrial control systems.[1, 2] Motion control includes applications for speed and torque or position control in practically all branches of industry. An important advance in this field has been made during the last years by the introduction of microprocessor control systems. These systems are becoming a standard in motion control because of fast advances in microelectronics technology and well-known benefits, such as: [2, 3, 4]

- Greater accuracy
- Flexibility
- Repeatability
- Less noise
- Parameter sensitivity
- Higher interconnection capacity

As a consequence of this progress, more and more applications that have used simple electric drives for economic reasons are being replaced by motion control systems. This is a natural evolution considering the benefits offered by motion control systems in meeting the ever-increasing needs for improved quality and greater productivity in all industries.

To facilitate this move towards motion control solutions, efforts are being made to continuously decrease the cost of these systems, especially considering their power electronics and control parts.

# Motion Control System Requirements

Figure 1 presents the basic structure of a typical motion control system, which consists of:

- Electric motor (M)
- Power electronic block (PE)
- Digital control system (DCS)

The inputs to the digital controller are the reference quantity *y* and the process values, which are measured with a set of sensors and generally converted using analogue-to-digital (A/D) converters. These values are electrical (voltage *V,* current *I)* and mechanical (velocity $\omega$, position $\theta$) signals.

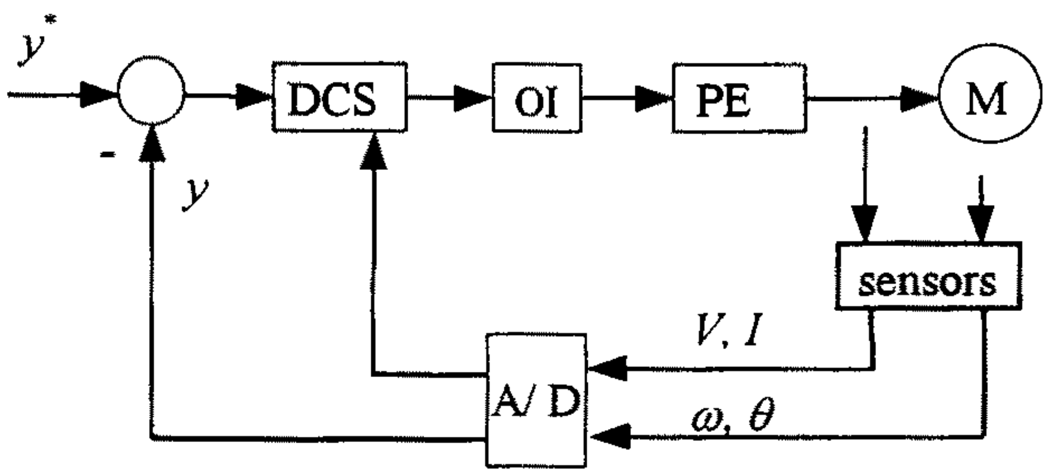
The DCS controls the PE through an output interface (OI). This interface consists of digital to analogue (D/A) converters, if the PE requires an analogue input, or of a simple isolation module, if the DCS directly controls the PE switching elements (transistors, IGBTs, etc.).

The requirements for such a system are demanding regarding steady state accuracy and dynamic behavior, sensitivity to external disturbances, measurement noise and parameter variation, and especially reliability and cost.

Inevitably, more and more quantities must be controlled simultaneously (position and/or speed, acceleration, torque, and current). All of these quantities are changing rapidly enough that the sampling time must be very small (typically in the range of 0.1 to 1 ms). Some of these quantities are measured; others can be estimated.

Invariably, there are analog inputs. The number of inputs can range from 5 to 8 for complex systems. This means that the microprocessor system must read the information from the corresponding sensors. Precision depends on the accuracy of the sensors and the converters. Typically these converters must have 10 or more bits of accuracy and a conversion time maximum of 10 µs.

*Figure 1. Basic Structure of a Typical Motion Control System*

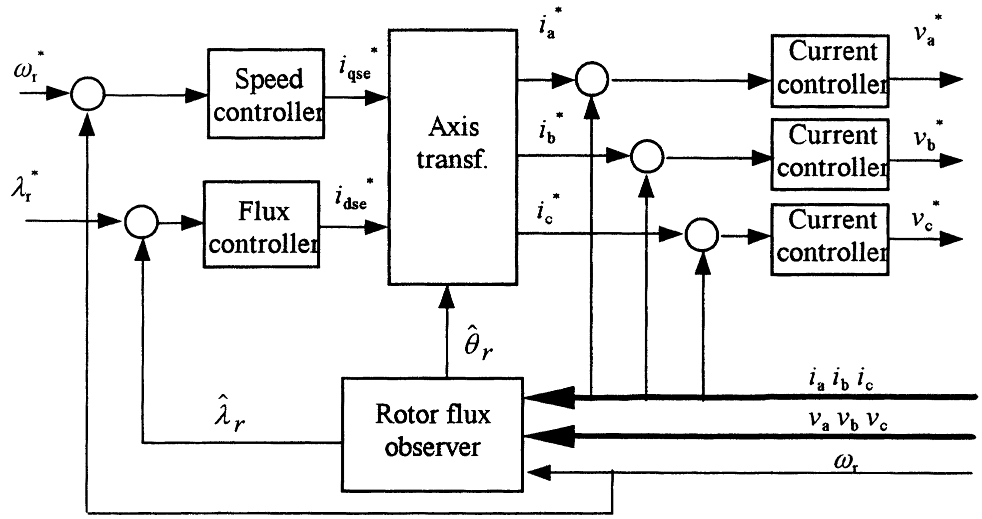



Note: DCS – digital control system; M – electric motor; PE – power electronics; OI – output interface.

The extreme demands imply that sophisticated control algorithms must be executed in each sampling step. The control scheme of motion control systems is typically complex, even if the controller block is a simple PID (as it is in numerous applications).

For example, Figure 2 depicts the diagram of a popular induction motor control principle, the direct rotor flux orientation.[2, 3] The complexity of this scheme derives from the induction motor, which is a nonlinear element. To linearize the induction motor, the equations must be reported to the rotor flux frame. The reference currents obtained in this way must be expressed in the stator frame so that the PE can be controlled.

*Figure 2. Induction Motor Based on Direct Rotor Flux Orientation Principle*




Control diagram complexity differs with the motor type and the system performance.

In many cases the simple PID controller is replaced by more sophisticated schemes, such as adaptive or optimal controllers, to obtain an improved behavior even when parameters change or disturbances occur.

Furthermore, the control scheme can become more complex if quantities necessary for control are estimated rather than measured. In this way the corresponding sensors are eliminated and the system becomes cheaper and more robust.

If analog control is completely eliminated, the digital control system must generate the switching commands for the PE elements. Depending on the motor and PE type, these commands must be computed following a specific algorithm.

For example, a so-called pulse width modulation (PWM) strategy is usually employed for AC motors. The output value can be converted to the corresponding switching sequence either by software or hardware. The hardware solution is more complex but faster.

Aside from the motion control, the microprocessor system must communicate with other systems to receive commands and return process information. This usually requires a special motion control language consisting of a collection of instructions processed by the control system. The microprocessor thus receives the reference not as an array of values but as concise information used to construct an exact profile.

A DSP is frequently used to accomplish such a large number of computations in the small sampling time (0.1 to 1 ms) provided. The DSP solution offers sophisticated control schemes with very good performance.

Because cost is an important restriction for most industrial applications, the scheme must be carefully chosen. An optimum solution must be balanced between the requirement for high performance and the cost of the microprocessor control system.

The cost of a DSP control system depends not only on the cost of the DSP but also the cost of external components (converters, filters, memory, specialized inputs and outputs such as an encoder and a PWM).

## Fixed Point Vs Floating Point DSPs in Motion Control

Floating point DSPs from the TI TMS320C3x family are more attractive for a motion control system because their computational power and accuracy is higher than the fixed point TMS320C1x, TMS320C2x, or TMS320C5x. Although the achievable number of instructions per second is only slightly higher than that of the fixed point DSP in TMS320C5x family (30 vs 28 MIPS), their speed in floating point operation is impressive: 60 MFLOPS.[5, 6, 7, 8, 9] The computation accuracy is also much higher because the TMS320C3x has a 32 bit data bus.

In a floating point DSP, all variables can be represented as physical values, and every mathematical operation is directly described. Most of the software can be written in C.

For a fixed point DSP on the other hand, all quantities (data, constants) are represented by integers in the -32768: 32767 range. This means that each must be converted to fit within this range. In addition, every mathematical operation must be performed so that the result is maintained within this range. This must be done without decreasing accuracy. Special techniques, such as the Q15 representation, are used to meet these requirements. The software development process is longer and more difficult. Furthermore an important part of the solution must be written in assembly language to perform Q15 operations and increase execution speed.

Thus, with floating point processors, sophisticated control algorithms can be implemented easier and faster and more accurately than with fixed-point processors. Nevertheless, good motion control can be implemented with fixed point DSPs, as will be demonstrated in the following paragraphs.

Although an economical floating point processor is available in the TMS320C32, the cost of a control system based on these processors is still higher than a system based on fixed point DSPs. For many applications in industry and consumer goods, fixed-point solutions will be preferred in the near future.

## Example: PID Control Using Fixed and Floating Point DSPs

One of the simplest controller algorithms employed in motion control is the discrete PID, with a transfer function given by:

$$u = k_p \varepsilon + k_1 \frac{\varepsilon}{z-1} + k_d \frac{z-1}{z-r} \varepsilon$$

with $k_p$, $k_I$, and $k_d$, (the coefficients of the proportional, integral, and derivative parts) and $r$ (a derivative filter coefficient).

In a floating point implementation, the operations executed by the DSP are those resulting directly from the above equation, with the input $\varepsilon$ , output $u$, and all coefficients expressed in their real values. To avoid wind-up, attention must be given to saturate the output $u$ according to the motor and power electronics limitations and to stop the integration when $u$ is saturated.

In a fixed-point implementation, several scaling operations are required to assure the Q15 of correct representation for all quantities.

This means that the equation is modified so that the input, output, and coefficients become less than unity. These operations are done off-line, require a certain skill, and must be repeated each time a controller coefficient or process parameter is changed. After the DSP solves the modified form of the above equation, the output must be multiplied by the same scaling factors to calculate the result.

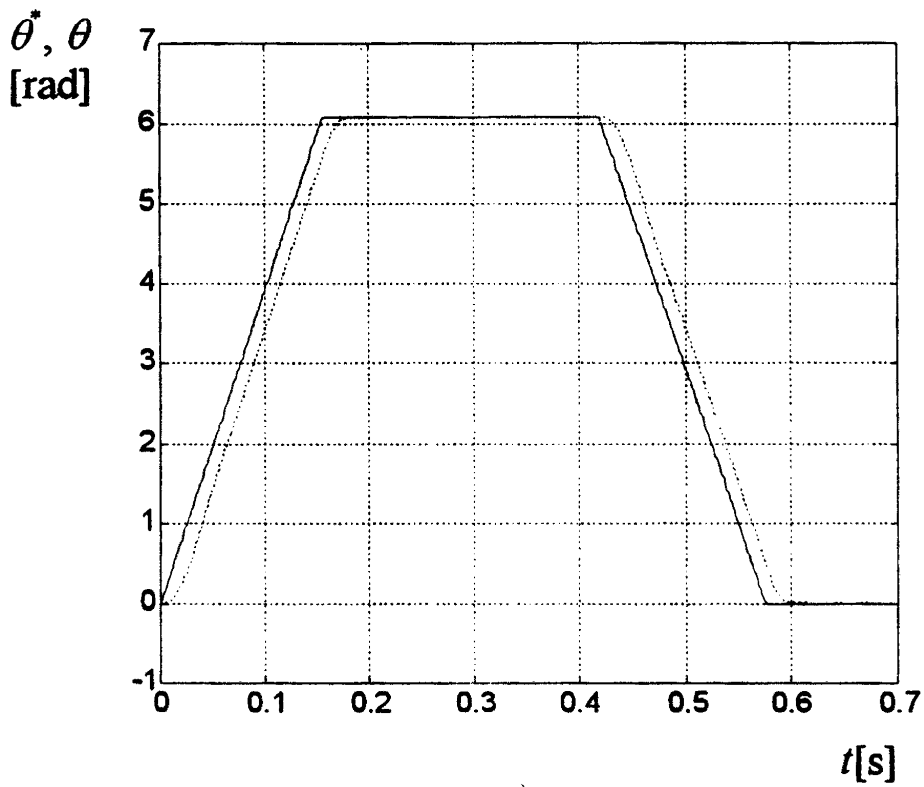
A fixed-point processor implementation is more convenient to use because it supports a version of the algorithm that simplifies the operations and increases computational accuracy.

## Experimental Results

Motion control systems using DSPs in the TMS320C1x, TMS320C2x, and TMS320C3x families have been designed and built by the authors. These systems employ various electric motors (DC, brushless, induction, and step) and are applied in high performance applications requiring speed or position control.[10, 11, 12, 13, 14, 15, 16]

Figure 3 and Figure 4 show the results obtained in a positioning system using a DC motor supplied from a chopper and controlled by a TMS320C14 DSP. The controller is designed for step reference and has a PID structure. However, system behavior is good even for a ramp reference. There is no stationary error when the reference is constant.

*Figure 3. Experimental Results for a DC Motor Motion System Controlled by a TMS320C14-Based System (Reference and Real Position)*




Note: Dotted line represents reference and real position.

*Figure 4. Experimental Results for a DC Motor Motion System Controlled by a TMS320C14-Based System (Motor Speed)*

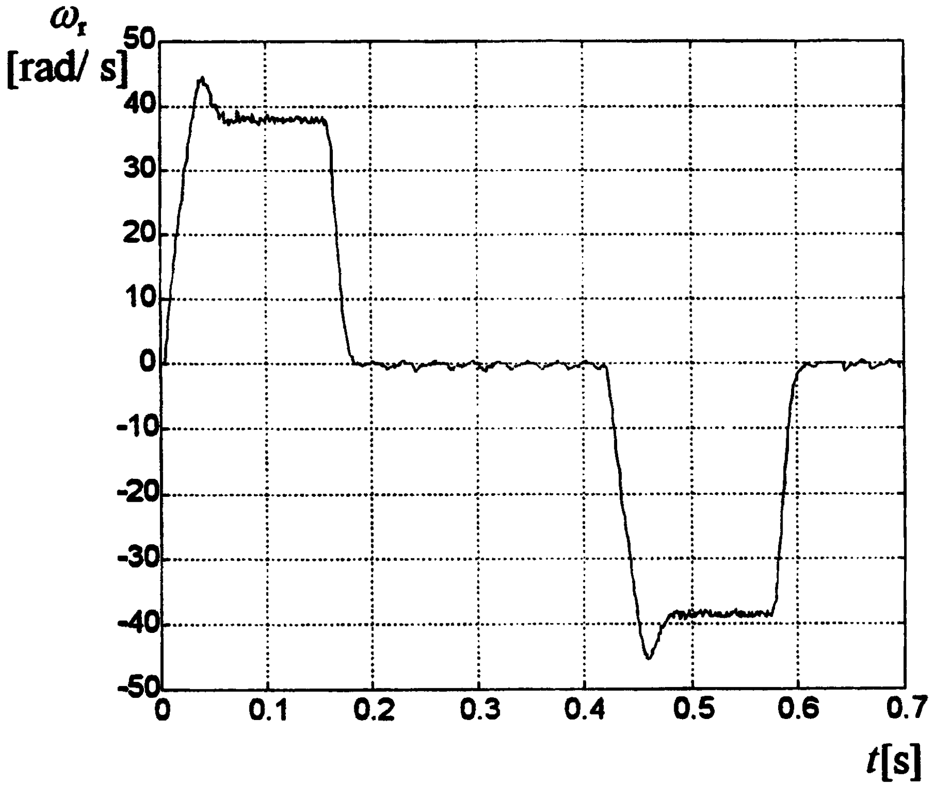



Figure 5 and Figure 6 show the results of a motion system using a brushless motor and a TMS320C25-based controller working at a sampling rate of 4 kHz.

The quantity to be controlled is the speed and the reference is a step. The rising time is given by the mechanical inertia with the torque being limited to its maximum value.

*Figure 5. Experimental Results for a Brushless Motor Motion System Controlled by a TMS320C25-Based System (Reference and Real Speed)*

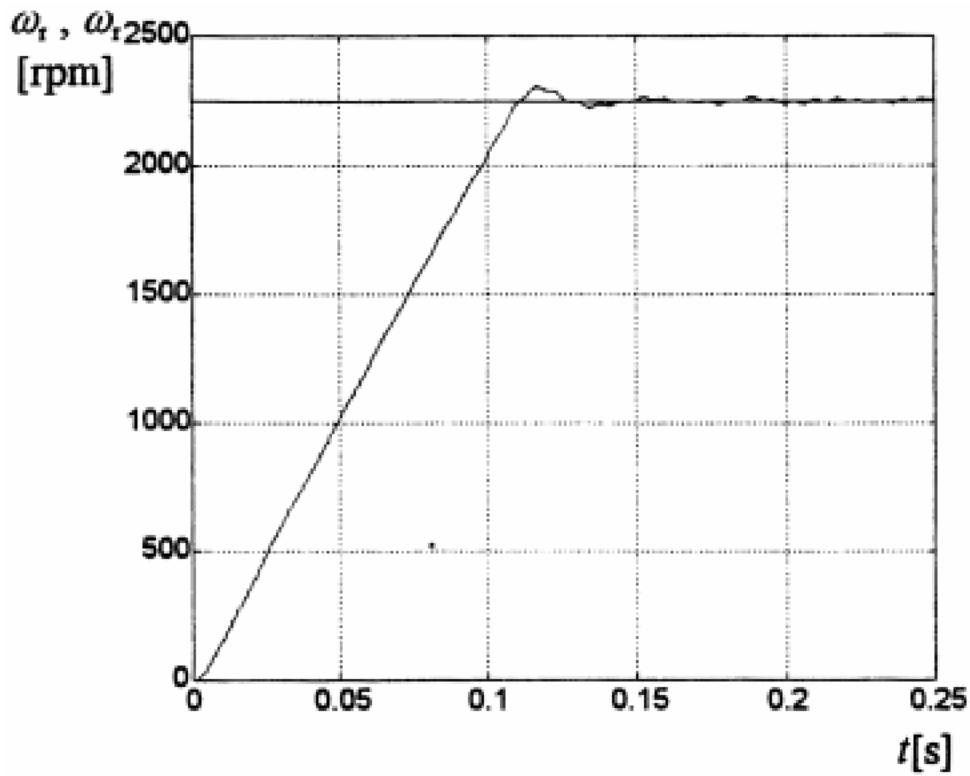


*Figure 6. Experimental Results for a DC Motor Motion System Controlled by a TMS320C14-Based System (Torgue Producing Current)*

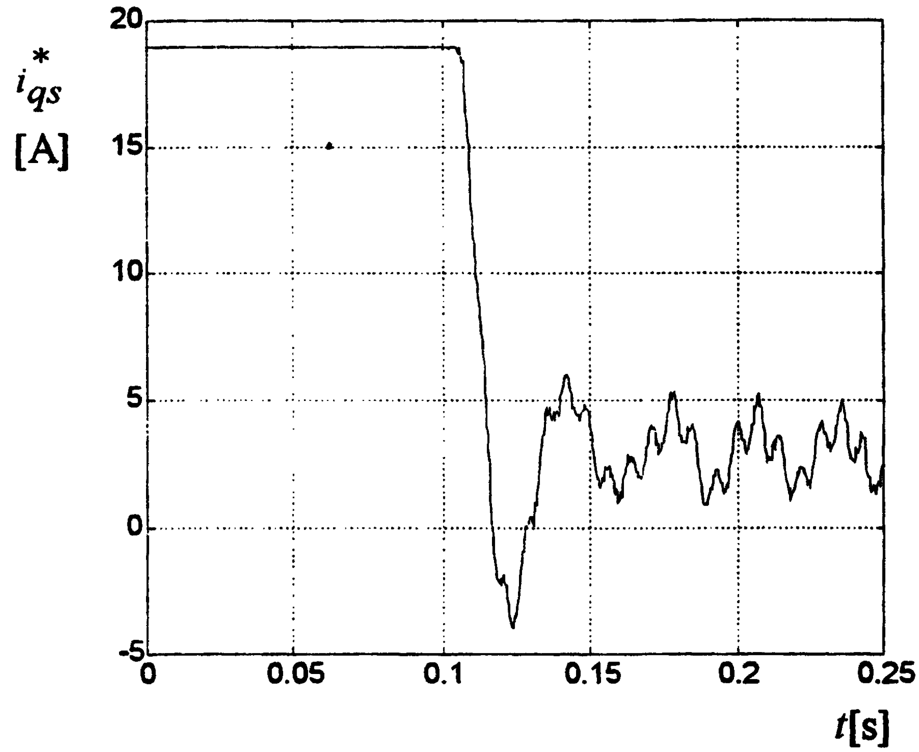
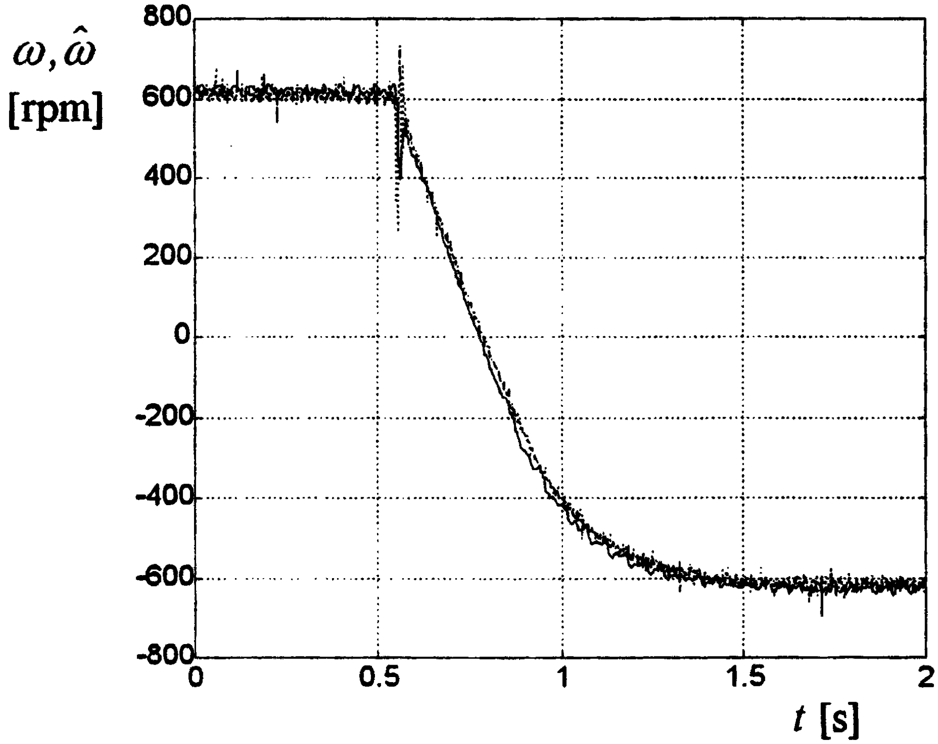



Figure 7 through Figure 9 present the experimental results for a sensorless field-oriented control of an induction motor system. In this control, the highly dynamic performance of a classical flux orientation is maintained; however, instead of measuring the speed (the quantity to be controlled), the speed is estimated from stator currents and voltages.

*Figure 7. Results for a Sensorless Motor Motion System Controlled by a TMS320C31-Based System (Real and Estimated Speed)*




Note: Dotted line represents real speed.

By removing the speed sensor, the system becomes simpler and more robust, but the control scheme is made even more complex than that shown in Figure 2. Indeed, instead of a rotor flux observer, it is now a flux and speed observer. Actually, it is an adaptive flux and current observer in which the speed is a parameter continuously changing so that the error between the real and the estimated current is maintained at a minimum.

A floating point TMS320C31 DSP was used because of the huge number of computations required in a very short time (the sampling frequency is 5 kHz). The results show that the difference in the actual and estimated speed and currents is at a minimum, which means that the rotor flux is within acceptable limits.

*Figure 8. Results for a Sensorless Motor Motion System Controlled by a TMS320C31-Based System (Estimated Rotor Flux)*

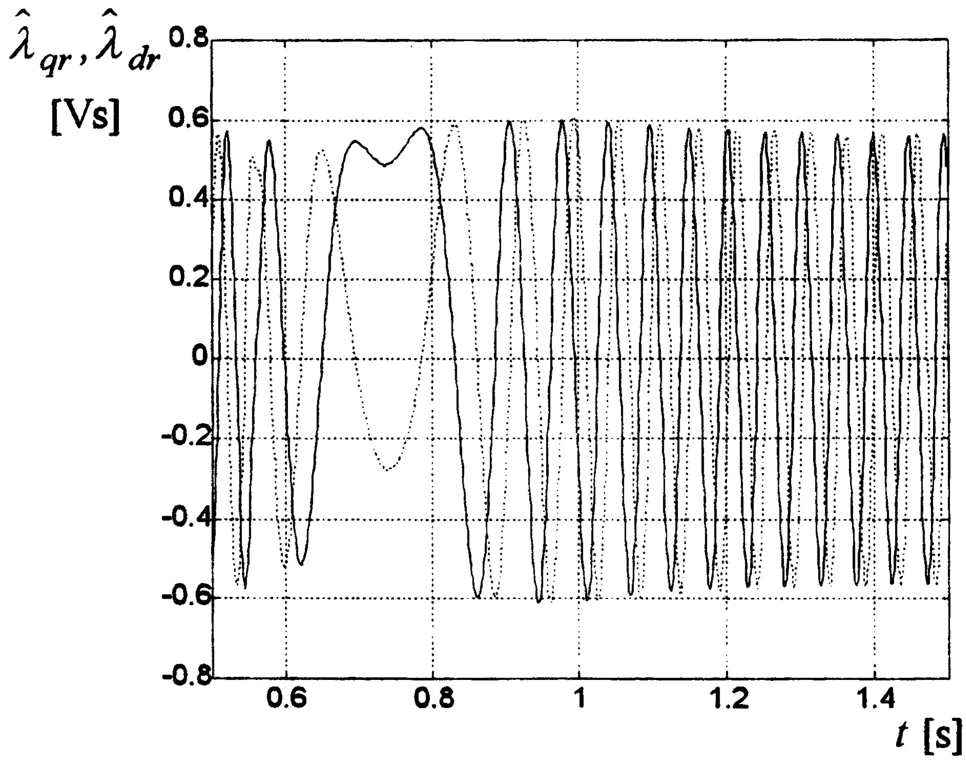


*Figure 9. Results for a Sensorless Motor Motion System Controlled by a TMS320C31-Based System (Real and Estimated Stator Current on Stationary Q Axis)*

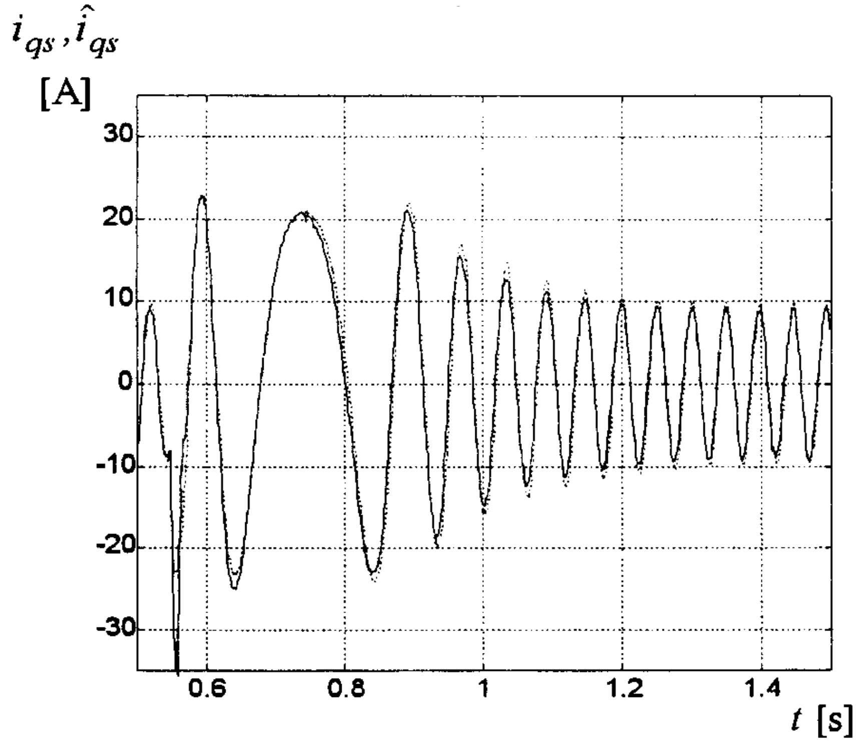



Figure 10 shows the experimental results for a positioning system with a step motor controlled by a TMS320C25 DSP. This system was required to advance a given number of steps in the minimum possible time.

*Figure 10. Experimental Results for a Step Motor Motion System Controlled by a C25-Based System (Position)*

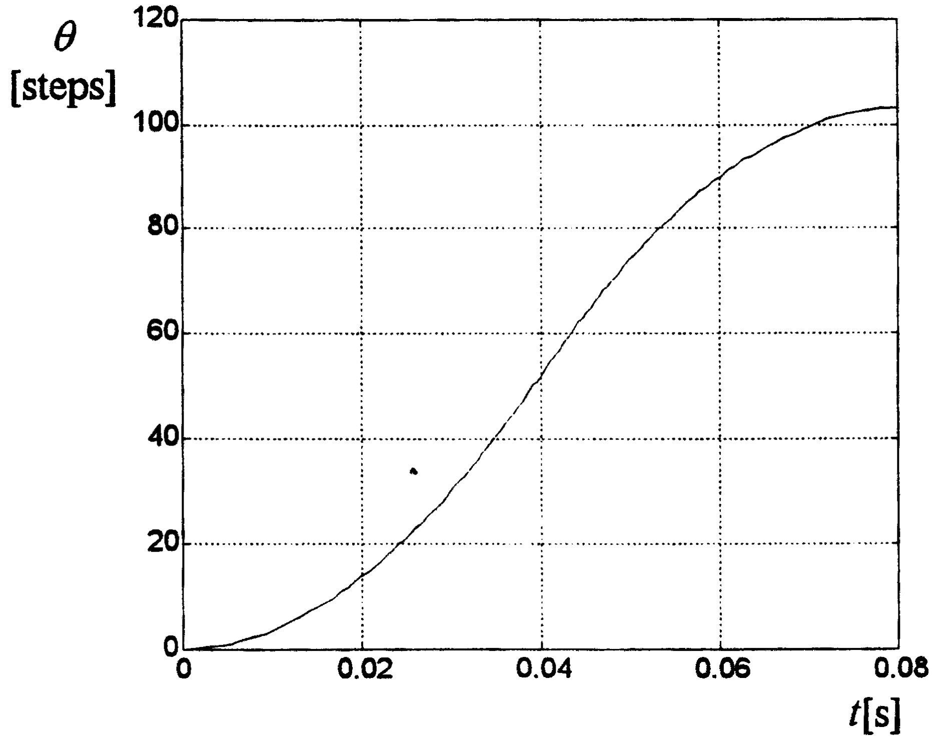
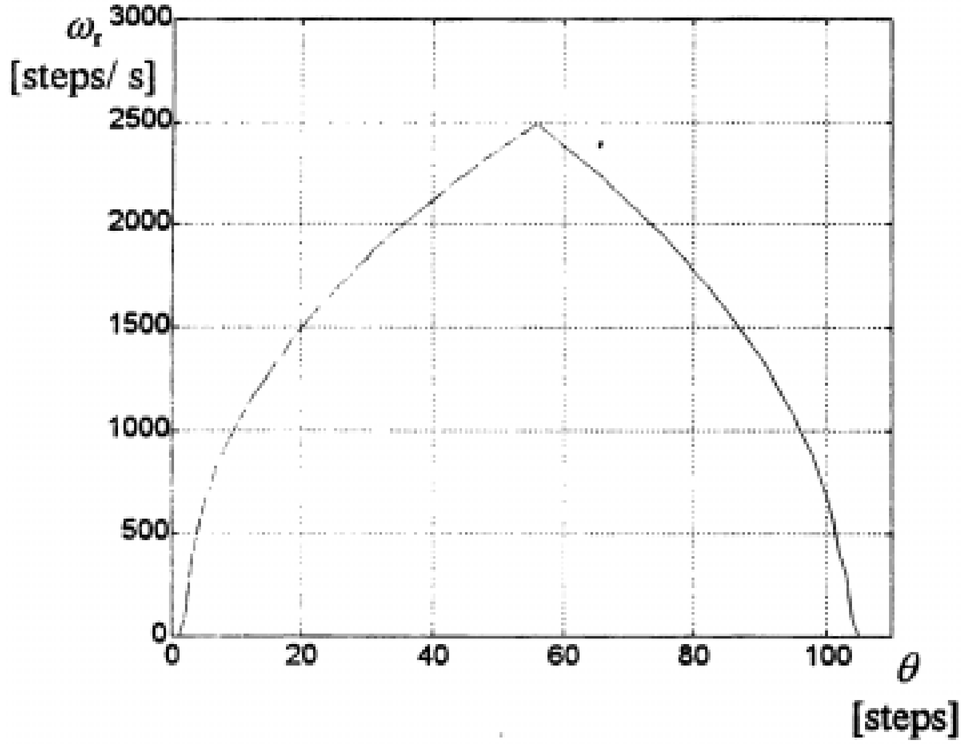


*Figure 11. Experimental Results for a Step Motor Motion System Controlled by a C25-Based System (Motor Speed vs. Position)*




It is evident that the precision and dynamic performance for DC step and brushless motors are very good even with fixed point processors. For the induction motor, a field-oriented control and simple sensorless operation can also be obtained with fixed point DSPs. Nevertheless, for very complex algorithms aiming for a precise estimation of rotor flux, speed and other parameters, a TMS320C3x is preferred.

## Intelligent Motor Concept

A strong tendency in the field of motion control is to integrate the motor, the power converter, and the control electronics in a single, compact unit.[1] This is possible because the size of power electronics is constantly being reduced. An intelligent motor is thus obtained with an extremely simple implementation, increased reliability, and reduced cost.[1] This trend clearly implies the necessity of having compact control electronics and, if possible, a single chip containing the DSP core as well as memory, converters, and specialized inputs and outputs. The first step was accomplished almost ten years ago when the TMS320C14 and TMS320E14 were launched,[6] but people from the motion control industry were expecting a new generation product with a more powerful core, larger RAM and ROM, and more peripherals (especially A/D and D/A converters).

## Summary

This application report discussed the main aspects related to the use of DSPs in motion control systems. Starting from the typical applications requirements, the characteristics of the DSP-based control systems were defined. Different solutions using DSPs in the TMS320 DSP family were presented. Special attention was paid to the comparison between fixed and floating-point processors. Experimental results for all of the main types of electric motors (DC, brushless, induction, and step) and processors in the TMS320C1x, TMS320C2x and TMS320C3x families were presented.

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