Using the TMS320C24X DSP Controller for Optimal Digital Control

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Abstract

Although traditional microcontrollers include the necessary peripherals to provide solutions for digital control applications, they lack both the performance and architecture needed to perform real-time, math-intensive, advanced control algorithms at a desired bandwidth.

This application report describes the features of the Texas Instruments (TI™) TMS320C24x digital signal processor (DSP), a low cost, single chip solution for optimal digital control system applications. This solution is a tribute to the integration of not only a powerful DSP core, but also to its specialized digital control circuit (known as the *event manager*) and a comprehensive set of desired peripherals.

Because of the high bandwidth signal processing ability of the DSP, this DSP controller can help designers easily achieve a robust, precise, adaptive, and sensorless digital control system.

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Introduction

Saving energy has become a key concern because of the continuing increase in energy usage. Increased efficiency reduces capital spending by utility companies building additional power plants, which in turn reduces utility costs for customers. To remain competitive, power plant administrators are pressured not only to reduce costs imposed by governments and power plant lobbies, but also to answer to power consumption reduction and EMI radiation reduction issues.

These constraining factors result in the need for enhanced algorithms. In addition to system cost reduction, DSP technology makes digital control more practical and also offers a high level of performance.

The TI TMS320C240 DSP is part of a new generation of processors addressing digital motor control and power conversion optimization. The TMS320C240 is specifically designed for the digital motor control and power conversion segments, combining a 16 bit fixed-point DSP core with microcontroller peripherals in a single chip solution.

Analog Vs Digital Control Systems

Early solid state controls consisted of hardwired analog networks built around operational amplifiers. Analog controls offer two distinct advantages over digital systems:

- Higher speed control by processing input data in real time
- Higher resolution over wider bandwidths because of infinite sampling rates

However, there are several drawbacks to analog systems:

- Aging and temperature can cause component variations, which in turn causes the system to need regular adjustment.
- Analog systems have more physical parts than digital systems, which reduces reliability and makes analog systems more difficult to design (component tolerance issues).
- Upgrades are difficult because the design is hardwired.

Benefits of Microcontrollers

- Drift is eliminated since most functions are performed digitally.
- Upgrades are easily made in software.

- Part count is reduced because the microcontroller can handle several functions on-chip. Microcontrollers are good for systems that do not require high speed or precision.

Benefits of DSP-Based Control

The TMS320C24x DSP includes the same advantages as the microcontroller but also offers higher speed, higher resolution, and capabilities to implement the math-intensive algorithms to lower the system cost. The high speed is attributable mainly to the dual bus of the Harvard architecture as well as single-cycle multiplication and addition instructions. One bus is used for data and the other is used for program instructions. This saves time because each is utilized simultaneously. Traditionally, cost has been a potential disadvantage of the DSP solution, but this aspect has diminished with the continuing decline of DSP costs.

DSP controllers enable enhanced, real-time algorithms as well as sensorless control. The combination reduces the number of components and optimizes the design of silicon to achieve a system cost reduction.

DSPs are capable of processing data at much faster rates than microcontrollers. For example, the speed of the DSP allows it to estimate motor velocity, a task accomplished by a tachometer in analog and microcontroller systems.

DSP-based controls offer the following additional benefits:

- Sharp-cutoff notch filters that eliminate narrow-band mechanical resonance. Notch filters remove energy that would otherwise excite resonant modes and possibly make the system unstable.
- Diagnostic monitoring achieved by the fast Fourier transform (FFT) of spectrum analysis. By observing the frequency spectrum of mechanical vibrations, failure modes can be predicted in early stages.
- Adaptive control by having the speed to monitor and control the system concurrently. A dynamic control algorithm adapts itself in real time to variations in system behavior.

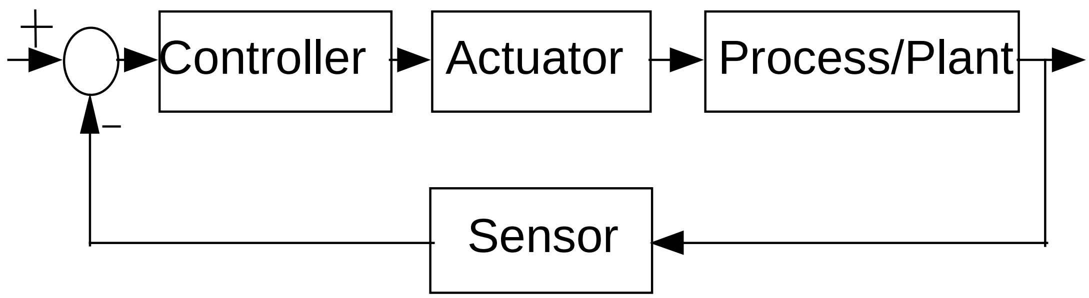
  For example, FFT data can be used to tune notch filters to track and eliminate vibrational modes as they vary with system speed, weight, balance, or other parameters.
- System cost reduction by an efficient control in all speed ranges, implying right dimensioning of power device circuits
- High level algorithms from reduced torque ripple, which results in lower vibration and longer life

- Reduced harmonics using enhanced algorithms to meet easier requirements and reduce filter costs
- Remove speed or position sensors by implementing sensorless algorithms
- Reduce the number of look-up tables, which reduces the amount of memory needed
- Real-time generation of smooth, near-optimal reference profiles and move trajectories, which results in better-performance
- Control power switching inverters and generate high-resolution PWM outputs
- Single chip control system

Control System

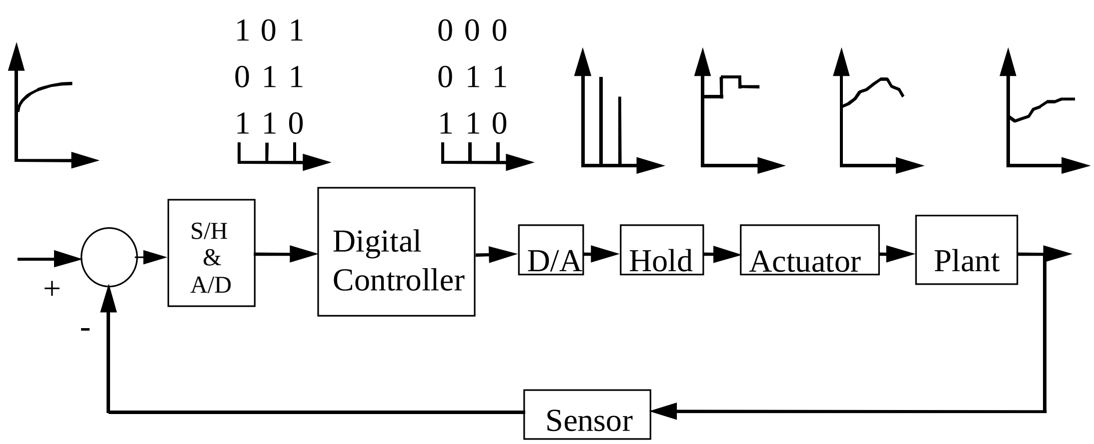
In general, a control system consists of a plant (or process), controller, sensors, and actuators. A typical control system is shown in Figure 1. To achieve the desired output, the control system commands or regulates the plant, thus allowing the output to behave as expected.

Figure 1. Typical Control System



As the performance and reliability of microprocessors increase, digital control system approaches have become more attractive for designers attempting to build their own solutions. The digital control system block diagram is shown in Figure 2.

Figure 2. Block Diagram of a Digital Control System



Digital Controller Requirements

The following list highlights the digital controller requirements.

- Calculations powerful enough to implement advanced and math-intensive control algorithms, such as

$$y(t) = \sum_{m=0}^{M} a(m)y(t-m) + \sum_{n=0}^{N} b(n)x(t-n)$$

- Fast response to events to obtain input signals and to unexpected events to secure the system
- Accurate resolution to minimize quantization errors; therefore, a precise digital control system is offered
- High sampling rate to avoid aliasing introduced by sampling effects
- Required peripherals to reduce CPU overhead and system cost

Processor Requirements

The following list highlights the processor requirements.

- Strong calculating power for advanced and math-intensive control algorithms
- Capability to support large word lengths for required resolution and dynamic range
- Small interrupt latency and fast branch operations capabilities to facilitate quick response to events, including unexpected events
- High-MIPS CPU to increase the range of the sampling frequency
- Integrate the application-specific peripherals with the processor, such as timers, A/D converters, PWM generators, and communication interfaces. Hence, CPU overhead and total system costs are reduced.

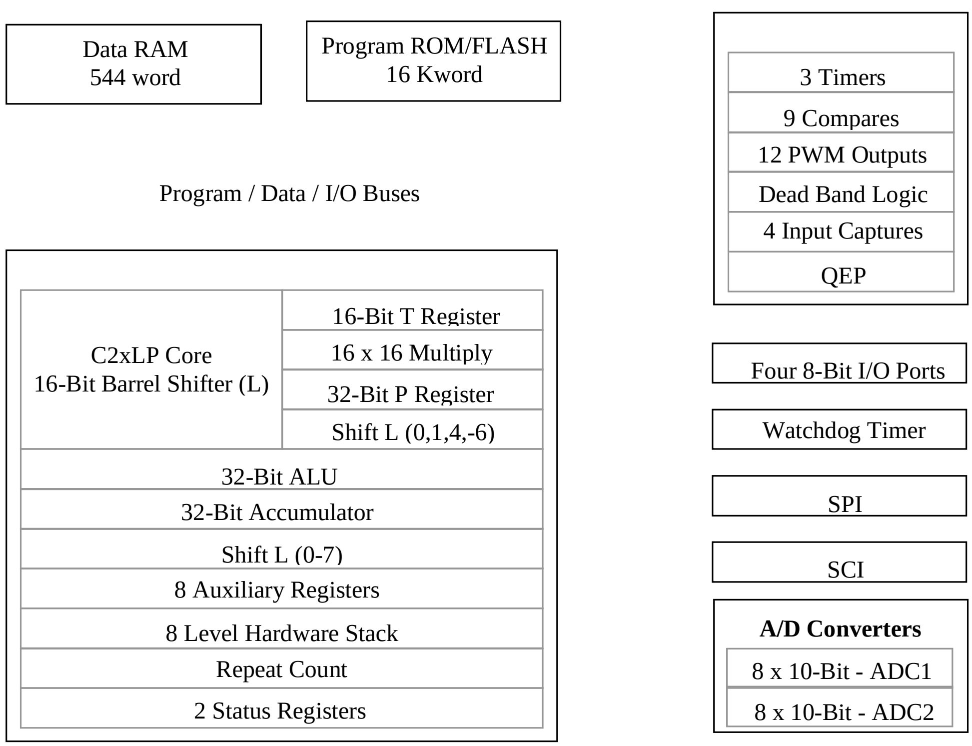
TI TMS320C24x DSP Family – the Optimal Digital Control System Solution

The TMS320C24x, the first single-chip DSP solution for the digital control system market, integrates the TI 16 bit, fixed-point TMS320C2xLP DSP core with several microcontroller peripherals. The DSP core itself has up to 20 MIPS (50 ns cycle time) speed and can perform the useful multiply/accumulate instruction in a single cycle.

The TMS320C240 has a 544-word data/program RAM and 16K-word program ROM. Although the TMS320F240 has the same amount of memory, the program ROM is Flash type. The totally external memory address reach of this family is 224K words (64K data, 64K program, 64K I/O, and 32K global memory). The architecture of the TMS320C240 DSP is shown in Figure 3.

The full set of powerful peripherals include an optimized event manager, two sets of analog-to-digital (A/D) converters on-chip, a watchdog timer, a serial communication interface (SCI), a serial peripheral interface (SPI), and four I/O ports.

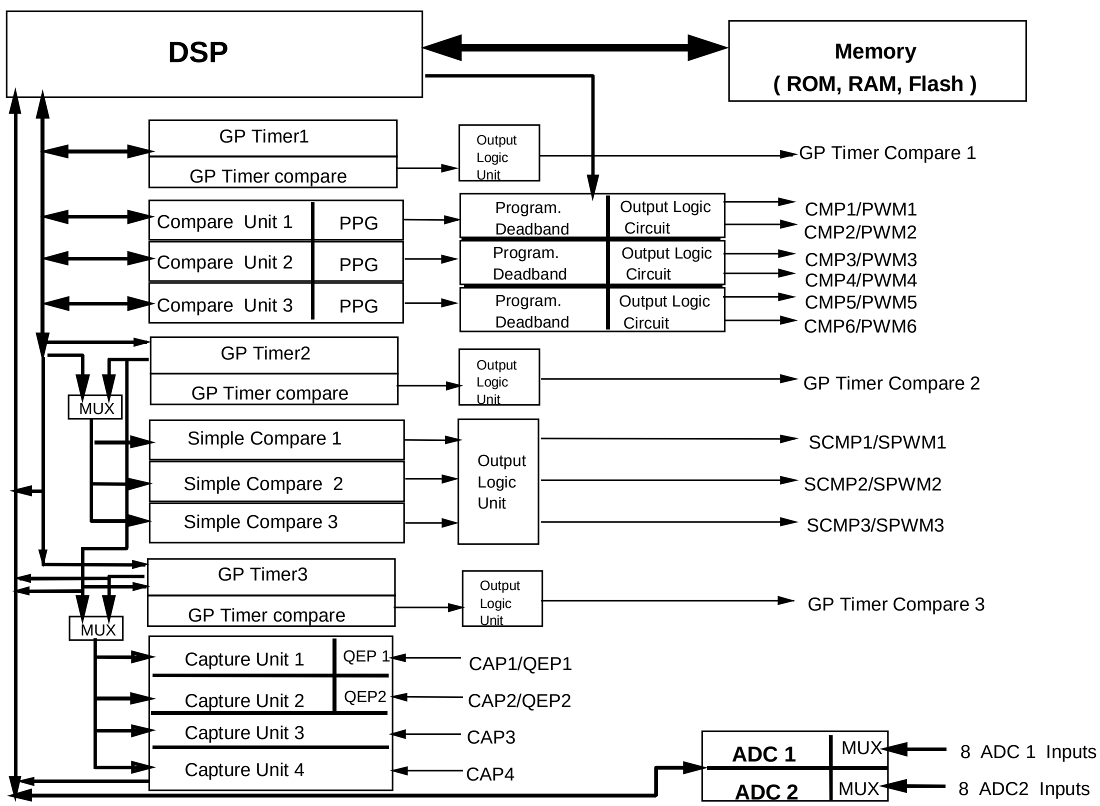
Figure 3. TMS320C240 DSP Architecture



The event manager module is shown in Figure 4. Features include three up/down timers and nine comparators that can create up to 12 PWM generation capabilities when coupled with flexible waveform generation logic. A space-vector PWM state machine implements an optimized scheme for switching power transistors, yielding longer transistor life span and lower power consumption.

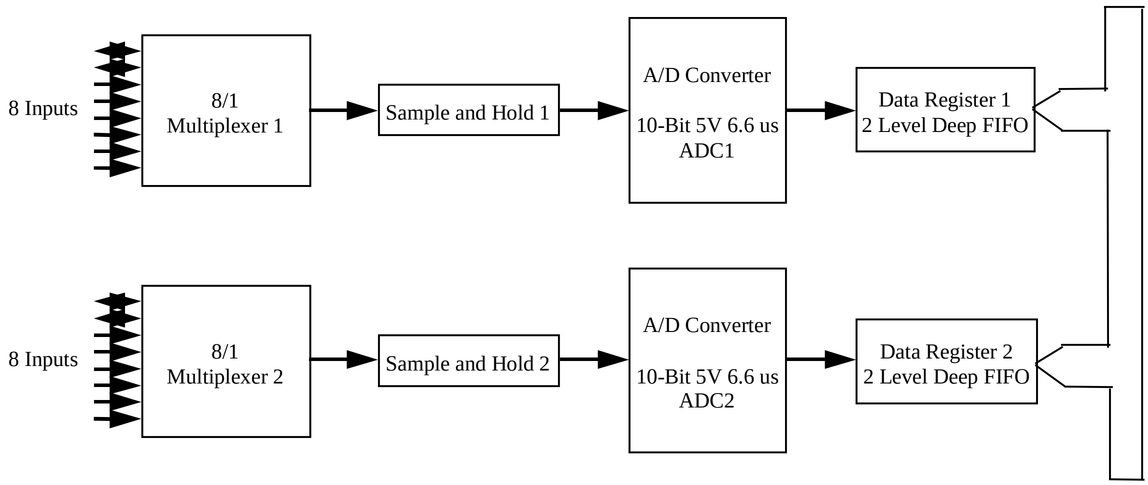
A dead-band generation unit helps protect power transistors. In addition, the event manager integrates four capture inputs, two of which can serve as direct inputs for optical-encoder quadrature pulses. In all, these features represent a state-of-art solution for flexible PWM generation and system control.

Figure 4. TMS320C240 Event Manager Module



Two sets of 10-bit A/D converters are available on-chip. As shown in Figure 5, each of the A/D converters provides 8-channel inputs. The two sample-and-holds allow parallel and simultaneous sampling and conversion. A new conversion starts immediately after the previous conversion is completed. A/D converters can begin conversion by software instruction, external signal transition on a device pin, or an event manager event. The conversion time is 6.6 µs.

Figure 5. TMS320C240 Analog-to-Digital Converter Module



Applications

DSPs are used for servo control of the actuator that drives the read/write head of disk drives. Data is read from the disk at a very high rate with sampling rates of up to 50 kHz. In addition to the compensator, DSPs can implement notch filters to attenuate undesirable frequencies that cause mechanical resonance or vibrations.

In AC servo drives, DSPs are used for vector control of AC motors. AC drives have complex control structures because of the cross coupling of the three-phase currents. Vector rotation techniques transform three-phase axes into rotating two-phase d-q axes. This two-phase rotation technique greatly simplifies the analysis, making it equivalent to analyzing field-wound DC motors.

In UPSs and power converters, DSPs are used for PWM generation as well as power factor correction and harmonic elimination. Advanced mathematical techniques can be used to control the firing angles of the inverters, creating low-harmonic PWM with unity power factors.

Three classical motors are among the existing electric motors on the market:

- DC with commutators (wound field)
- Synchronous AC motor
- Asynchronous AC motor

When properly controlled, these classical motors produce constant instantaneous torque (very little torque ripple) and operate from pure DC or AC sine wave supplies. Unlike DC motors, the use of which is levelling off and even declining each year, the use of AC motors is increasing each year. A couple of reasons for this increase are possible: AC motors cost less than DC motors and, AC motors can be controlled more easily using digital control (especially DSPs).

For example, brushless permanent magnet synchronous motors (PMSM) include a vector control approach in which matrix and vectors represent the control quantities. Using a MAC calculation unit included with the TMS320C24x DSP provides the following advantages:

- Full motor torque capability at low speed
- Better dynamic behavior

- Higher efficiency for each operation point in a wide speed range
- Decoupled control of torque and flux
- Short term overload capability
- Four quadrant operation

Sensoring or sensorless algorithms can also be implemented with DSPs. The most common way to sense motor speed on the shaft is to use an incremental encoder. The TMS320C240 includes a module, the quadrature encoder pulse (QEP), that handles the situation perfectly, calculating the speed and direction of the rotation using only two digital inputs and a 16- or 32-bit internal timer register.

In some applications emphasising efficiency, cost, reliability, and mechanics, it is not possible to use a speed, position, or Hall (commutation signals) sensor. In such situations, the necessary information can be derived from dynamic modelling applications such as sliding mode observer or Kalman filtering. In PMSM applications, a Kalman filter can be used for the estimation of speed and rotor position with only measurements of the motor voltages and currents.

DSPs also benefit automotive applications ranging from engine/transmission control, active suspension control, adaptive ride control, anti-lock brakes, and traction control. The performance of the current electronic engine control in power-train control applications can be improved by a closed loop control system. The system incorporates a DSP with sensors, such as in-cylinder pressure sensors, to control the precise operating status of each cylinder at every cycle.

The DSP in the system performs engine pressure waveform analysis and determines the best spark timing, firing angles, and optimal air/fuel ratios. Closed loop external turbulence, such as aging and wearing, maintain optimum engine performance and fuel efficiency.

Vehicle control applications benefit from active suspension that can help improve ride performance by introducing variable damping ratios into dampers. The TMS320C24x can also consider body dynamics, such as pitch, heave, and roll to control hydraulic actuators independently and dynamically to counter external forces and car attitude changes.

DSPs perform control algorithms with system parameters adaptively updated to achieve road handling and ride comfort. In ABS design, a microcontroller typically is incorporated to read the wheel speed from sensors, calculate the skid, and control pressure in the brake cylinders. In addition, traction control and diagnostics software will demand more processing capability on the traditional controller.

Summary

This application report presents a new controller architecture: the DSP controller and its single chip solutions for the control applications. The TI TMS320C240 DSP controller combines the performance of DSP architecture with the optimized peripherals of a microcontroller. With this DSP controller, an intelligent control and sensorless approach become possible. In addition, the system cost will be reduced and the reliability of the entire system will be improved.

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