How to Develop Real-Time Engine for Next-Generation Motor Control?

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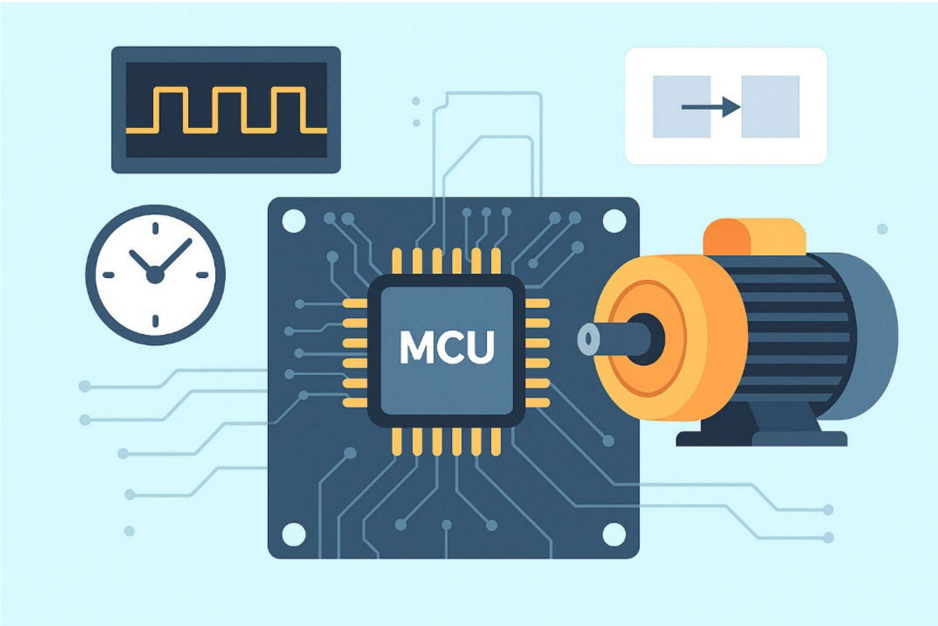

Abstract

One of the most important technical elements in a motor control system is real-time performance, as it can enhance efficiency, precision and responsiveness. However, with the diversifying market needs, motor control controllers must perform various processes in parallel, such as overall system control of the equipment, communication with other devices, and user interface control, in addition to motor control. This white paper will explain how the functional features and user benefits of the newly released RA8T2 MCUs are designed to solve these issues.

Pursuit of Performance as A Real-Time Engine

Do you know the difference between a MCU (Micro Controller Unit) and a MPU (Micro Processor Unit)? Both are semiconductor devices equipped with a CPU (Central Processing Unit), but there are some differences. First of all, although they have a common architecture centered on the CPU and memory executing instructions and processes data, they differ in terms of performance. The MCUs have 8 to 32-bit CPUs with tens to hundreds of MHz, while MPUs have 32 to 64-bit CPUs with hundreds of MHz to several GHz, which are much faster. In terms of memory, MCUs have built-in flash memory and SRAM, while MPUs generally have external flash memory for program storage and large-capacity SDRAM. Each is used according to the requirements of the target application. MCUs are often used in motor control applications such as fans and pumps where the load fluctuation is small and the rotation speed does not fluctuate greatly, while MPUs are used in motor control applications such as AC drives and AC servos in industrial equipment controlling large motors that require high-speed control of rotation speed, torque and vibration control.

	MCU	MPU
CPU Frequency	▪ 8 to 32-bit CPU ▪ Several tens of MHz to several hundred MHz	▪ 32 to 64-bit CPU ▪ Several hundred MHz to several GHz
Memories	▪ Built-in flash memory and SRAM ▪ Some products offer the chance to use additional external memory	▪ External flash memory and , built-in SRAM ▪ Easy to expand with external SDRAM, etc. ▪ Memory latency is improved with cache memory and TCM (Tightly Coupled Memory) for Arm CPUs
Uses and Benefits	▪ Extremely wide range of applications including consumer and industrial ▪ Lower price generally, due to smaller package sizes etc. than MPUs	▪ For specific consumer and industrial devices that require high performance ▪ More expensive generally, due to larger package size etc. than MCUs

Table 1. Main Differences between MCUs and MPUs

Real-time performance in motor control refers to the completion of a specific process within a stipulated time. In other words, while it is important that the process itself is fast, what is more important is to guarantee that the process is completed at the stipulated time with little variation in processing time. If real-time performance cannot be guaranteed, what will happen? Taking an example of a motor control system using an MCU or MPU. The inverter circuit is driven by PWM (Pulse Width Modulation) output using a built-in timer. This control method modulates the PWM output within a certain period for the command value (speed, position, torque) to generate the desired waveform and control the motor. If real-time performance cannot be maintained, this process will not be completed within the stipulated period and the PWM output will be unintended, causing motor to not operate according to the command value. In the worst case, the motor may lose synchronization and lead to an accident.

The CPU operating frequency of conventional MCUs is from tens to hundreds of MHz, and the built-in memory can be accessed at a frequency close to that, so it is possible to estimate the worst processing time and easily guarantee the real-time performance. On the other hand, MPUs have a shorter control cycle to improve control accuracy, and the CPU needs to operate at high speed. However, when a program is executed from an external flash memory, which is several times slower than the CPU, the memory speed becomes a limiting factor, and the original performance cannot be achieved. Therefore, as a general countermeasure, programs are placed in the built-in high-speed SRAM or TCM at startup; or cache memory is used to reduce access to the slow memory and achieve high-speed operation. On the other hand, placing all programs in SRAM or TCM is difficult from the capacity perspective, hence it is necessary to make use of the limited internal memory to reduce access to external flash memory and ensure real-time performance. This is a constant challenge for software developers of MPU-based motor control systems.

In response to this challenge, the RA8T2 is designed by combining the best of MCUs and MPUs to greatly contribute to the realization of high real-time control systems. Powered by an Arm Cortex-M85 core, the RA8T2 operates at 1GHz and achieves 6,390 CoreMark, which is the same level as an MPU. Similar to MPUs, it also has built-in cache memory, TCM, and SRAM, but it is significantly different from MPUs in that it is equipped with MRAM (Magnetoresistive Random Access Memory) for code as an MCU. This MRAM achieves zero-wait access up to 100MHz, equivalent to the 40nm process FMONOS, a high-speed flash memory previously developed by Renesas. This allows peak performance with TCM to be on par with MPU performance. Even if access to the built-in MRAM occurs, the MRAM continues to perform better than an external flash memory, making it easy to ensure real-time performance like conventional MCUs. In addition to performance, the built-in flash memory and SDRAM contribute to the miniaturization and system cost reduction. The elimination of the need for a dedicated external bus enables user to secure users IO pins even with a small number of pins.

The following figure 1 shows the results of measuring the processing performance of the RA motor control MCU based on a software developed by Renesas. In the same environment, we expect the performance to be twice as high as the RA8T1 (Cortex-M85, 480MHz).

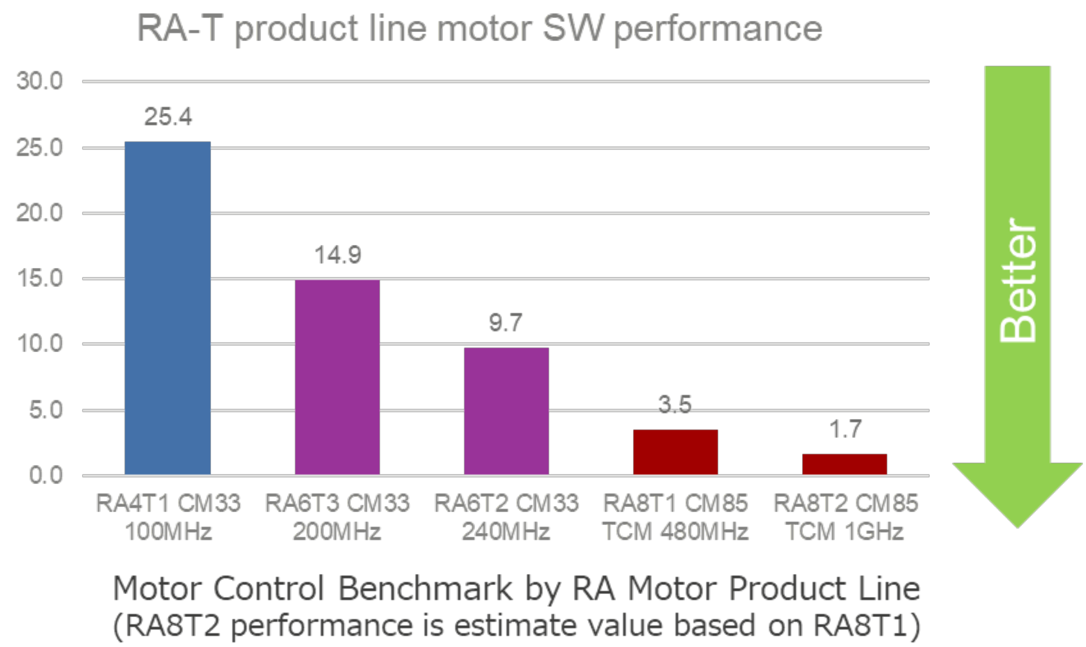

Figure 1. Motor Control Software Processing Performance of the Renesas RA-T Group MCUs

Ensuring Real-Time Performance on Dual-Core Systems

In the previous section, I explained the difference between MPUs and MCUs from the perspective of real-time performance, but there are still other challenges in motor control systems. High-end motor control devices do not simply control motors; other tasks such as system control and communication with other devices are added to the motor control depending on the application. In other words, real-time processing of motor control and other non-real-time processing must be executed in parallel. One approach to solving this problem is to select a device with higher processing power and execute it sequentially, but this is not the optimal solution because it increases cost and power consumption. Another approach is to use a multi-core system adopted in MPUs. This method is very effective in motor control applications, and it is common to assign tasks to each CPU core in advance to ensure real-time performance.

The RA8T2 of the Renesas RA Family MCU family provides the Arm Cortex-M85 and an optional Arm Cortex-M33 core in addition to build a dual-core system. Users can decide which CPU to install real-time processing on the motor control. As an example, let's consider the case where motor control processing is placed on the Cortex-M85 side (Figure 2). In a dual-core system, tasks are not simply assigned to each CPU, but the CPUs must communicate with each other while operating. For this reason, the built-in SRAM is used for both CPU calculations and shared memory between the two CPUs. The RA8T2 has a large capacity of 1.6MB excluding the TCM, which is sufficient for motor control and shared memory.

Now, let's look at the tasks of each CPU. The Cortex-M85 has a maximum of 1GHz and zero-wait TCM of 128KB for instructions and data, which is sufficient for normal motor control programs. Similarly, the Cortex-M33 side is assigned with system control, and its maximum operating frequency is 250MHz, which is also sufficient for general system control. With this configuration, motor control requiring real-time performance, and system control, which is non-real-time processing, can be separated through the SRAM, achieving complete parallel processing. This architecture enables high real-time performance on the motor control side and improves the system response and quality on the system control side.

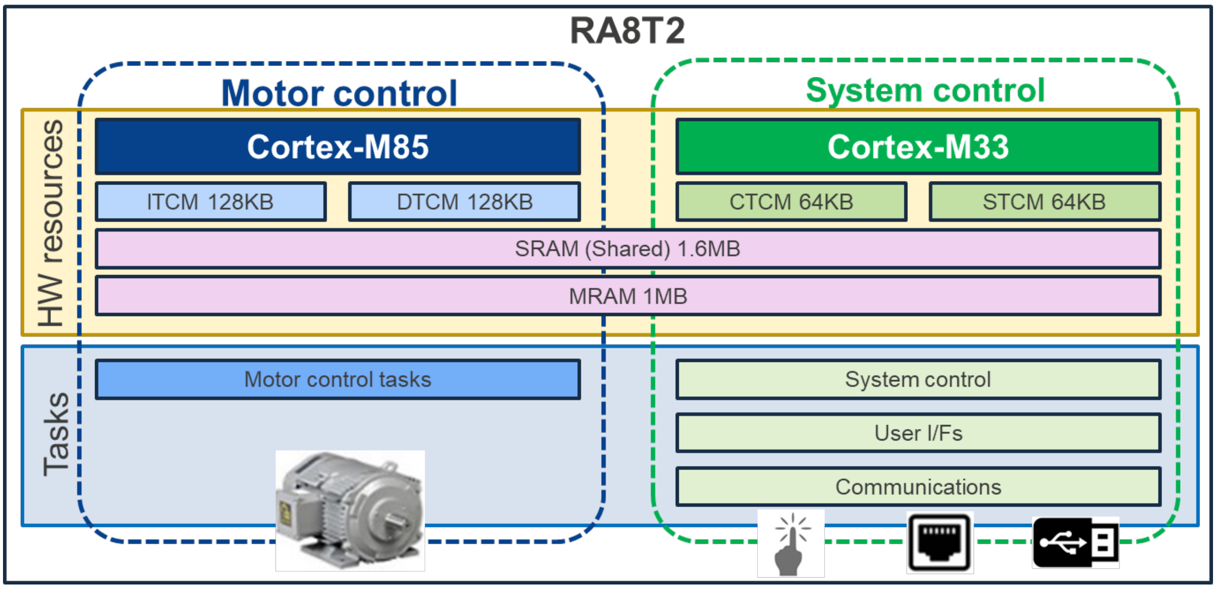

Figure 2. Example of Task Placement in a RA8T2 Dual-Core System

Industrial Ethernet Needs

In addition to CPU performance, let's look at the peripheral functions of the RA8T2. The RA8T2 utilizes the excellent 22nm process technology to reduce device costs while incorporating a variety of peripheral functions.

The PWM timer and AD converter, which have been proven as popular interfaces for motor control in Renesas MCUs to date, are further improved to deliver higher efficiency of motor control and implement new algorithms.

The RA8T2 also integrated new industrial Ethernet functions, which are highly demanded mainly in the industrial field. Industrial Ethernet is an Ethernet technology used for industry and has higher robustness and real-time performance than standard Ethernet used in offices. It is possible to send and receive data within a set time, enabling accurate send and receive of specific manufacturing data and execute operations within a factory. It provides various added value to motor control equipment, such as remote operation, synchronous operation, and equipment failure detection.

The RA8T2's Ethernet consists of a 2-channel Gigabit Ethernet controller with hardware switch function and a 2-channel EtherCat slave controller, which is the first to be installed in RA family of MCUs. The Gigabit Ethernet controller and switch have high-level routing functions and will support multi-protocol solutions such as TSN (Time Sensitive Networking), general-purpose Ethernet-based EtherNet/IP and PROFINET.

The Gigabit Ethernet controller supports Time Sensitive Networking (TSN), a technical standard that divides IEEE Ethernet-based data by time and controls communication bandwidth according to the priority of communication frames, something that was not possible with conventional standard Ethernet technology. Renesas plans to provide the following drivers, which are commonly used in industrial applications:

- IEEE 802.1AS: Synchronizes the time of devices connected to a network
- IEEE 802.1Qbv: Classifies communication frames and allocates priority communication bandwidth
- IEEE 802.1Qbu: Interrupts communication of low-priority Ethernet frames to allow transmission of high-priority frames

In addition to the above-mentioned drivers, future driver support is planned for enhanced functionality to improve communication robustness. The EtherCAT slave controller also ported logic developed by Germany's Beckhoff Automation GmbH. The topology is a daisy chain, enabling high-speed and highly accurate synchronous control. As mentioned above, Ethernet and EtherCAT processing can be assigned to the Cortex-M33 side for dual-core system, which is effective in applications that require synchronous control while maintaining high real-time performance for multiple motors such as robots and semiconductor manufacturing equipment.

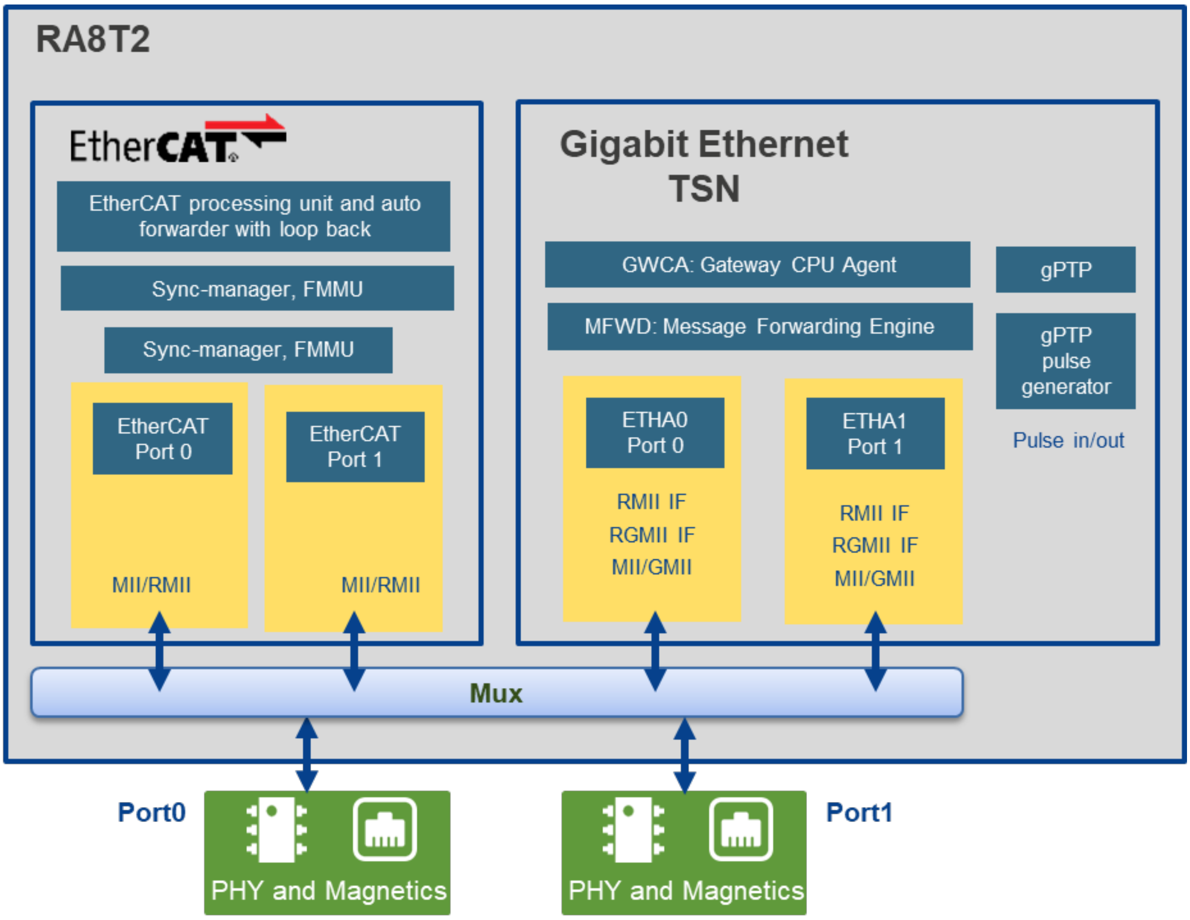

Figure 3. Built-In Ethernet Network System Configuration of RA8T2

Motor System Development Solutions

Building an environment to evaluate MPU-class motor control systems is not easy. As performance improves and number of functions increase, the board must handle high-speed signals, and motor control signals that handle high voltages and large currents placed in proximity, resulting in more care and consideration need to be put into while working on the layout, wiring, and noise care. In addition to component placement, motor control systems require the development of power stages such as inverter circuits, and circuit development takes a longer time than with general systems. The MCK-RA8T2 is a hardware reference kit enabling developers to jumpstart evaluation and development with circuit information included as a design package to reduce the development time.

All Components for Rotating a Motor in One Package

The MCK-RA8T2 can directly connect the inverter board to the CPU board equipped with the RA8T2 and various IFs via a connector. A BLDC motor is also included in the MCK, enabling users to rotate the motor as soon as they open the box. To support a quick initial evaluation and development, users manual and quick start guide are provided to the users. Communication card is also included in the package and enables users to connect to the

CPU board via an isolator, to safely evaluate motor control and debug in an environment where the PC and CPU board are electrically isolated. Combine this communication card with the motor control development support tool – RMW (Renesas Motor Workbench) – users can read and write variables inside the MCU, identify motor parameters, and obtain control parameters used in vector control.

Figure 4. MCK-RA8T2 Image

Kit Name	MCK-RA8T2
Part Number	RTK0EMA6L0S00020BJ
CPU	RA8T2 (R7KA8T2LFLCAC) Dual core CM85 and CM33, MRAM 1MB / RAM 2MB, w/ EtherCAT BGA289
Included Items	Inverter Board (RTK0EM0000B12020BJ) CPU Board (RTK0EMA6L0C00000BJ) Communication board (RTK0EMXC90Z00000BJ) Brushless DC Motor (Rated voltage：36[V], Rated current：1.67[A])
I/Fs	USB connector for J-Link On-Board USB connector for RA8T2 SCI connector for Renesas Motor Workbench communication CAN communication (Through holes) 20-pin through hole for Arm debugger PMOD connectors (Type2A + Type3A/6A) Ether CAT connector MicroSD slot DSMIF

Table 2. MCK-RA8T2 Overview

Application Notes and Sample Code

Renesas provides RA8T2 specific application notes and sample code for controlling various motors. Users can download these documents from the Renesas website according to the motor type and control algorithm. Users can find summarized software control contents such as 120-degree conduction method and sensorless vector that operate various motors; detailed functions and control flow that are very useful for users' development and evaluation. Also, each application note comes with sample code that can be downloaded to the RA8T2. The sample code uses various package software and drivers and uses MCK-RA8T2 as the target board. For motor control sample codes, it mainly includes control algorithms, system control, PWM control, and AD conversion.

Currently, the following application notes for motor control are released, and we will continue to release contents that support user development in the future.

Category	Title
Motor Control **Application Note** **Sample code**	Sensorless vector control for dual permanent magnetic synchronous motor
	Vector control for permanent magnetic synchronous motor with hall sensors
	Sensorless Vector Control for Permanent Magnet Synchronous Motor
	Sensorless Vector Control with one shunt for Permanent Magnet Synchronous Motor
	Vector Control for Permanent Magnet Synchronous Motor with Encoder
	Vector Control for Permanent Magnet Synchronous Motor with Inductive Sensor
	120-degree Conducting Control of Permanent Magnet Synchronous Motor with Hall Sensors
	Sensorless 120-degree Conducting Control of Permanent Magnet Synchronous Motor

Table 3. List of Application Notes and Sample Codes for RA8T2 MCU

Summary

The RA8T2 MCU delivers MPU- level of performance for motor control applications that are becoming more complex and multifunctional for the next generation. In addition to its excellent performance, the dual-core system enables full parallel execution of real-time and non-real-time processing. From a functionality viewpoint, RA8T2 provides both optimized motor control functions, and powerful built-in industrial Ethernet function that enables networking of user systems and linkage with other devices in a compact footprint. Renesas provides users with a variety of evaluation and development solutions equipped with the RA8T2 MCUs, enabling them to develop cost-effective and high-performance, highly functional motor control equipment systems in a short period of time. In addition to high-performance MCUs for motor control, Renesas also has a strong portfolio of low-end and mid-end MCUs engineered for motor control applications at all levels. With the fast-changing market demands, developers can scale their development with ease and acceleration from high-end to low-end MCUs using similar development environment. Explore Renesas’ RA-T series MCUs specially designed for motor-control applications.

References

RA8T2: 1GHz Arm® Cortex® -M85 Microcontroller Optimized for Motor Control Applications

MCK-RA8T2: A development kit that enables easy evaluation of motor control using permanent magnet synchronous motors (brushless DC motors)

RA MCU Family: 32-bit MCUs equipped with Arm Cortex-M cores

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