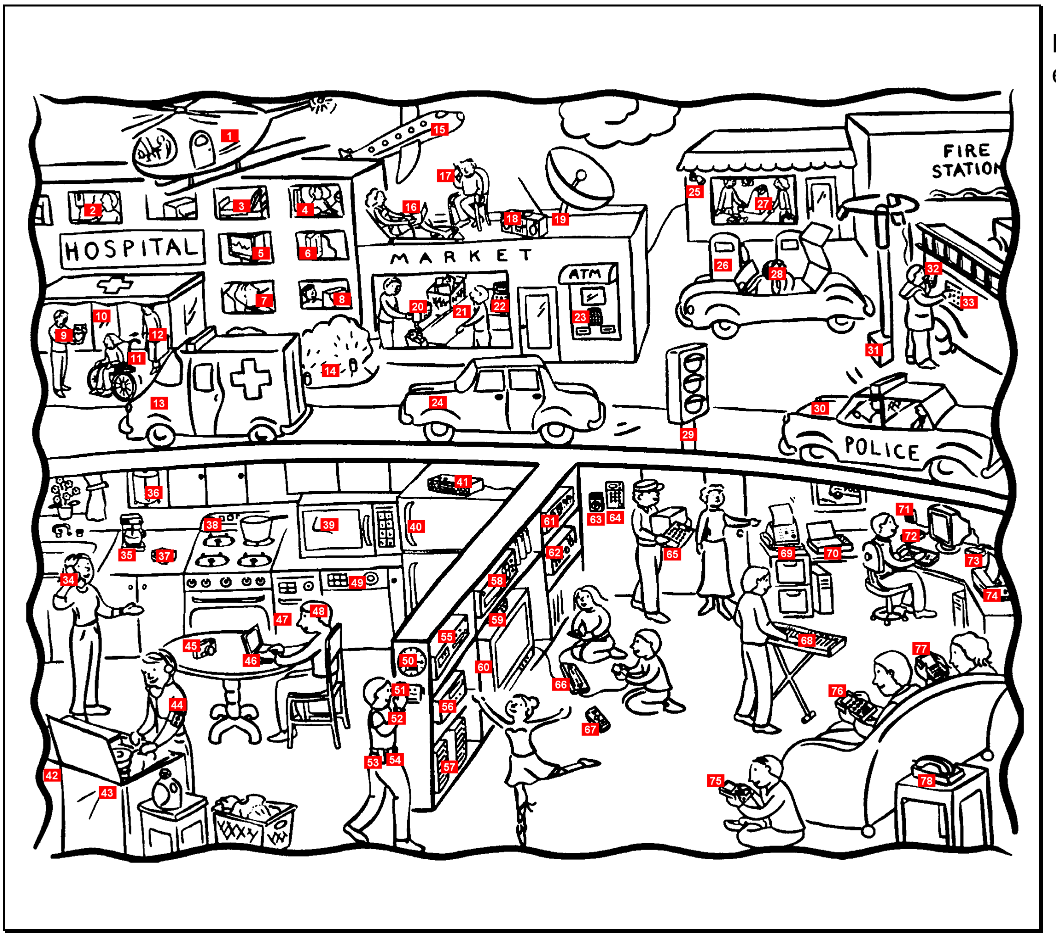
Lecture 1 – Embedded Systems

Embedded systems characteristics. The Freescale Tower.

Introduction

Computing systems are everywhere. Billions of computing systems are built every year that are embedded within larger electronic devices, repeatedly carrying out a particular function, often going completely unrecognized by the device's user.

A quick look around our environment turns up embedded systems in a surprising number of places. The picture below shows just a few such systems in common environments.



Examples of embedded systems

Figure 1.1

1.2

A listing of these systems is given below:

Outdoors

1. Helicopter: control, navigation, communication , etc.
2. Medicine administering systems
3. Smart hospital bed with sensors and communication
4. Patient monitoring system
5. Surgical displays
6. Ventilator
7. Digital thermometer
8. Portable data entry systems
9. Pacemaker
10. Automatic door
11. Electric wheelchair
12. Smart briefcase with fingerprint enabled lock
13. Ambulance: medical and communication equipment
14. Automatic irrigation systems
15. Jet aircraft: control, navigation, communication, autopilot, collision-avoidance, in-flight entertainment, passenger telephones, etc.
16. Laptop computer (contains embedded systems)
17. Mobile telephone
18. Portable stereo
19. Satellite receiver system
20. Credit / debit card reader
21. Barcode scanner
22. Cash register
23. Automatic teller machine
24. Car (engine control, cruise control, temperature control, music system, anti-lock brakes, active suspension, navigation, toll transponder, etc.)
25. Automatic lighting
26. Pump monitoring system
27. Lottery ticket dispenser
28. Pager
29. Traffic light controller

Indoors

34. Cordless phone
35. Coffee maker
36. Rice cooker
37. Portable radio
38. Programmable oven
39. Microwave oven
40. Smart refrigerator
41. In-home computer network router
42. Clothes dryer
43. Clothes washing machine
44. Portable MP3 player
45. Digital camera
46. Electronic book
47. Garbage compactor
48. Hearing aid
49. Dishwasher
50. Electronic clock
51. Video camera
52. Electronic wristwatch
53. Pager
54. Mobile phone
55. CD player
56. DVD player
57. Smart speakers
58. Stereo receiver
59. TV set-top box
60. Television
61. PVR
62. TV-based Web access box
63. House temperature control
64. Home alarm system
65. Point-of-sale system
66. Video-game console
67. TV remote control
68. Electronic keyboard
69. Fax machine
70. Scanner

30. Police car (data lookup, communication, sirens, radar, etc.)
31. Mobile phone base station
32. Hand-held communicator (walkie-talkie)
33. Fire-control onboard computer
71. Wireless networking
72. Telephone modem
73. ADSL modem
74. Printer
75. Portable video game
76. Personal digital assistant
77. Portable digital picture viewer
78. Phone with answering machine

Nearly any device that runs on electricity either already has or soon will have a computing system embedded within it. In 2011, 500 million smart phones, 60 million tablet PCs and 25 million eReaders were shipped.[1]

Embedded Systems Characteristics

Embedded systems have several common characteristics that distinguish such systems from other computing systems:

1. *Single-functioned*: An embedded system usually executes a specific program repeatedly.
2. *Tightly constrained*: Embedded systems often must cost just a few dollars, must be sized to fit on a single chip, must perform fast enough to process data in real time, must consume minimum power to extend battery life, and must be designed rapidly to capture market windows.
3. *Reactive and real-time*: Many embedded systems must continually react to changes in the system's environment and must compute certain results in real time without delay.

[1] http://blogs.freescale.com/2012/03/13/the-mobile-revolution-is-over-the-evolution-has-just-begun/ (Accessed 2012-03-16)

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The Freescale Tower

Freescale is a semiconductor company which broke away from Motorola in 2004. It was acquired by NXP (a break-away semiconductor company of Philips) in 2015. The brand-name “Freescale” is still in current use

The Freescale Tower is a modular system that allows for a variety of microcontroller boards and peripheral boards to be mixed-and-matched. The UTS Embedded Software Lab has a Freescale Tower system called the TWR-K70F120M-KIT, which has a TWR-K70F120M microcontroller board, a TWR-SER board, and two “elevator” boards:

The Freescale TWR-K70F120M tower

Figure 1.2

We will call the complete development system “the Tower” and the individual boards by their Freescale part names.

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The TWR-K70F120M

The TWR-K70F120M module carries a Kinetis MK70FN1M0VMJ12 micrcontroller unit (MCU), an on-board JTAG debug circuit with a virtual serial port, 1Gib[2] of dynamic RAM, 2 Gib of Flash memory, a three-axis accelerometer, four LEDs, four capacitive touch pads, two pushbuttons, a potentiometer and a Micro-SD card slot:

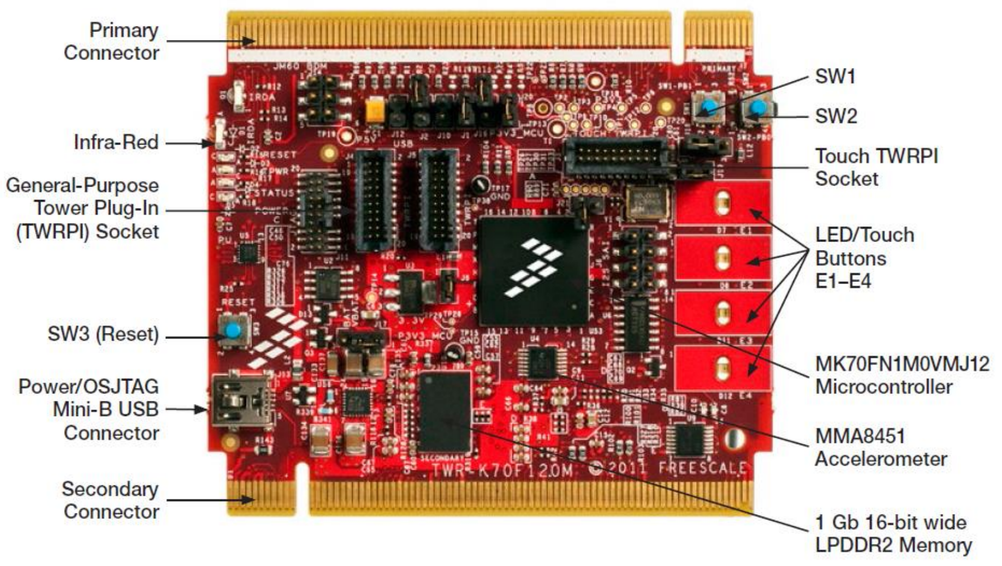

Figure 1.3

Refer to Freescale 's TWR-K70F120M Tower Module User's Manual for more information:

http://cache.freescale.com/files/microcontrollers/doc/user_guide/TWRK70F120MUM.pdf

[2] The gibibit, abbreviated Gib, is a multiple of the unit "bit" used to quantify digital information. It is a member of the set of units with binary prefixes defined by the International Electrotechnical Commission (IEC). The prefix gibi (symbol Gi) represents 1024^3, or 1 073 741 824.

The Kinetis MK70FN1M0VMJ12 Mircrontroller Unit (MCU)

Kinetis is a family of Freescale microcontroller units (MCUs) that are based on the extremely popular 32-bit ARM Cortex-M series of embedded processors. ARM developed these processors primarily for the microcontroller domain where the need for fast, highly deterministic interrupt management is coupled with extremely low gate count and lowest possible power consumption. For more information on the ARM Cortex-M Series of processors, see:

http://www.arm.com/products/processors/cortex-m/index.php

ARM states that:

The Cortex-M family is optimized for cost and power sensitive MCU and mixed-signal devices for applications such as Internet of Things, connectivity, motor control, smart metering, human interface devices, automotive and industrial control systems, domestic household appliances, consumer products and medical instrumentation.[3]

ARM licenses the processor design to silicon vendors who then make custom micrcocontrollers by adding their own peripherals, memory, etc. There is a huge "ecosystem" surrounding ARM processors because of their popularity – most mobile phones have an ARM processor, as does the Microsoft Surface, the Apple iPad, and the Raspberry Pi.

The Kinetis MK70FN1M0VMJ12 (hereafter abbreviated "K70") is based on the Cortex-M4F, which implements the ARMv7E-M architecture. This is a "high-end" processor (for a microcontroller) that supports digital signal processing (DSP) instructions, single instruction multiple data (SIMD) instructions, and contains a hardware single precision floating-point unit (FPU). For more information on the ARM Cortex-M4, see:

http://www.arm.com/products/processors/cortex-m/cortex-m4-processor.php

[3] http://www.arm.com/products/processors/cortex-m/index.php (Accessed 2015-07-24)

The K70 boasts an impressive array of system features and peripherals:

Module	Brief Description
Core	
ARM Cortex-M4	As of 2015, the newest member of ARM's Cortex-M series of processors.
Floating point unit (FPU)	A single-precision FPU that is compliant to the IEEE Standard for Floating-Point Arithmetic (IEEE 754).
Nested Vectored Interrupt Controller (NVIC)	The NVIC supports many interrupts, exceptions, and priority levels.
AWIC	The AWIC detects wake-up events.
Debug Interface	Four debug interfaces are supported.
System	
System integration module (SIM)	System integration logic and module settings.
System mode controller (SMC)	Provides control and protection on entry and exit to each power mode, and for resets.
Power management controller (PMC)	Provides the user with multiple power options.
Low-leakage wakeup unit (LLWU)	Allows the device to wake from low leakage power modes.
Miscellaneous control module (MCM)	Includes integration logic and embedded trace buffer details.
Crossbar switch (XBS)	The XBS connects bus masters and bus slaves.
Memory protection unit (MPU)	The MPU provides memory protection and task allocation.
Peripheral bridge	Allows the XBS to interface peripherals.
Direct memory access (DMA) controller	Provides for data movement without the CPU.
DMA multiplexer (DMAMUX)	Selects from many DMA requests down to a smaller number for the DMA controller.
External watchdog monitor (EWM)	Monitors both internal and external system operation for fail conditions.
Software watchdog (WDOG)	Monitors internal system operation and forces a reset in case of failure.

Table continues on the next page…

Memories and Memory Interfaces	
Flash memory	Program flash memory – non-volatile memory that can execute program code.
Flash memory controller	Manages the interface between the device and the on-chip flash memory.
Static Random Access Memory (SRAM)	Internal system RAM.
Local memory controller	Control access to RAM and the cache.
System register file	32-byte register file power by VDD.
VBAT register file	32-byte register file power by VBAT.
Serial programming interface (EzPort)	Provides the ability to read, erase, and program Flash memory and to reset and boot the system after flash programming.
FlexBus	External bus interface that support SRAM, PROM, EPROM, EEPROM, Flash and other peripherals.
NAND flash controller	NAND Flash interface.
Synchronous dynamic random access memory (SDRAM) Controller	Interface to store and retrieve data from an external SDRAM.
Clocks	
Multi-clock generator (MCG)	Provides several clock sources for the MCU including: - a phase-locked loop (PLL) - a frequency-locked loop (FLL) - internal reference clocks
System oscillator	The system oscillator, in conjunction with an external crystal or resonator, generates a reference clock for the MCU.
Real-time clock (RTC) oscillator	The RTC oscillator has an independent power supply and supports a 32 kHz crystal oscillator.

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Security and Integrity Modules	
Cryptographic acceleration unit (CAU)	Supports DES, 3DES, AES, MD5, SHA-1, and SHA-256 algorithms via simple C calls.
Random number generator (RNG)	Supports the key generation algorithm defined in the Digital Signature Standard.
Cyclic Redundancy Check (CRC)	The CRC generator can be used for error detection for all single, double, odd, and most multi-bit errors.
DryIce (tamper detection and secure storage)	Provides secure memory that is asynchronously erased on any tamper detect.
Analog Modules	
16-bit analog-to-digital converter (ADC) and programmable-gain amplifier (PGA)	16-bit successive-approximation ADC designed with integrated PGA.
Analog comparator (CMP)	Compares two analog input voltages across the full range of the supply voltage.
6-bit digital-to-analog converter (DAC)	Provides a selectable voltage reference.
12-bit digital-to-analog converter (DAC)	Low-power general-purpose DAC, whose output can be placed on an external pin.
Voltage reference (VREF)	Supplies an accurate voltage output that is trimmable in 0.5 mV steps.
Timer Modules	
Programmable delay block (PDB)	16-bit counter that is initiated by a trigger event and provides for flexible delayed output signals.
Flexible timer module (FTM)	16-bit counter flexible counter with input capture, output compare and PWM.
Periodic interrupt timers (PIT)	32-bit general purpose interrupt timer.
Low-power timer (LPTimer)	16-bit time or pulse counter with compare.
Carrier modulator timer (CMT)	Provides the means to generate the protocol timing and carrier signals for a wide variety of encoding schemes.
Real-time clock (RTC)	32-bit and 64-bit real-time clock with alarm.
IEEE 1588 timers	The 10/100 Ethernet module contains timers to provide IEEE 1588 time stamping.

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Communication Interfaces	
Ethernet MAC with IEEE 1588 capability (ENET)	10/100 Mbps Ethernet MAC with hardware support for IEEE 1588.
USB On-The-Go (OTG) (low-/full-speed)	USB 2.0 compliant module with support for host, device, and On-The-Go modes.
USB OTG (low-/full-/high-speed)	USB 2.0 compliant module with support for host, device, and On-The-Go modes.
USB Device Charger Detect (USBDCD)	Detects a smart charger meeting the USB Battery Charging Specification Rev 1.2.
USB voltage regulator	Powers on-chip USB subsystem.
Controller Area Network (CAN)	Supports the full implementation of the CAN Specification Version 2.0, Part B.
Serial peripheral interface (SPI)	Synchronous serial bus for communication to an external device.
Inter-integrated circuit (I2C)	Allows communication between a number of devices.
Universal asynchronous receiver / transmitter (UART)	Asynchronous serial bus communication interface with support for CEA709.1-B (Lon works) and the ISO 7816 smart card interface.
Secure Digital host controller (SDHC)	Interface between the host system and the SD, SDIO, MMC, or CE-ATA cards.
Inter-IC Sound (I2S)	Provides a synchronous audio interface (SAI) that supports full duplex serial interfaces such as AC97 and codec / DSP interfaces.
Human-Machine Interface	
General purpose input/output (GPIO)	General purpose pins.
Capacitive touch sense input (TSI)	Inputs for capacitive touch sensing applications.
Graphics LCD controller	Provides display data for external gray-scale or color LCD panels.

Table 1.1 – K70 Modules Grouped by Functional Categories

For more information, see the K70 Sub-Family Reference Manual:

http://cache.freescale.com/files/microcontrollers/doc/ref_manual/K70P256M150SF3RM.pdf