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Exercise for

Embedded Systems

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Sheet 1: Embedded Systems and Microcontrollers

Exercise 1: Questions

a) What is an embedded system?

Solution:

- A computer system (CPU, memory, software)
- which is integrated into another technical system "embedding system"
- influences the embedding system such that it behaves in the desired way

b) What is the source of requirements for an embedded system?

Solution:
Requirements are derived from the requirements of the embedd<u>ing</u> system.

c) Embedded systems can be categorized into two groups.

(1) What are these categories?
(2) What are their characteristics?
(3) What kind of hardware is typically used for these categories?
(4) Which programming languages are most dominant in these categories?
(5) Name at least one example for each category!

Solution:

1)	Product Automation	Production Automation
2)	many identical units cost per unit is critical customers aren't experts hardware determines platform	often only one identical unit cost is less critical costumers are close to being experts programming system is more important then the platform
3)	μCs, FPGAs	PLCs, Industrial PCs, Distributed Control Systems
4)	C/C++, Assembler, VHDL, Simulink	Instruction List (IL), SFC, ST, FBD
5)	Carengine Controller Washing Machine Controller Weather Station ...	Chemical Plant Controller Assembly Line Controllers ...

d) What is a microcontroller?

Solution:
A microprocessor with RAM, Permanent memory, Digital I/O and other peripherals.

Exercise 2: Digital I/O
For this and the following exercises we refer to the Atmel ATmega16 microcontroller. A datasheet can be found in the Moodle room.
Assume 8 buttons are connected to Port A and GND. Also assume 8 LEDs are connected to Port B and VCC (using fitting resistors) such that they can be lit.

a) What are the registers that control these ports?

Solution:
DDRA, DDRB: Data direction
PORTA, PORTB: Outputs / pull-up resistors
PINA, PINB: Inputs

b) How should these registers be initialized?

Solution:
DDRA = $(00000000)_2 = (00)_{16}$
DDRB = $(11111111)_2 = (FF)_{16}$
PORTA = $(11111111)_2 = (FF)_{16}$
PORTB = $(11111111)_2 = (FF)_{16}$
PINA, PINB are read only

c) Write a loop that allows control over the LEDs via the buttons:

(1) On a 1-to-1 basis (pushing button 4 causes LED 4 to be lit).

Solution:
```
while (1) {
    PORTB = PINA;
}
```

(2) Priority encoder: show the binary coding for the number of the highest button pushed.

Solution:
```
while (1) {
    int i;
    for (i=7; i>=0; i–) {;
        if(~PINA & (1<<i)){;
            PORTB=~i;
            break;
        };
    };
}
```

d) What is bouncing? Implement a debouncing method.

Solution:
Bouncing is short signal fluctuations before a signal change.
Example bouncing method:
```
uint8_t first, fail;
count = 3;
do {
    first = 1 & (PINA >> BTN_PIN);
    fail = 0;
    for(int i = 0; i < count; i++){
        if(first != (1 & (PINA >> BTN_PIN))){
            fail = 1;
            break;
        }
    }
}while(fail)
```

Exercise 3: Interrupts and Polling

a) Choose Interrupts or Polling for the following scenarios and explain your choice.

   (1) The ”change input”-button on a monitor
   (2) The wireless-reciever of a garage-opener
   (3) The keyboard on a standard desktop
   (4) The temperature-sensor of a weather-station

   Solution:
   1) Interrupts.
   2) Depends.
   3) Polling.
   4) Polling.

b) When is an ISR called and how is it done?

   Solution:
   Conditions: Global Interrupt Enable Bit, Specific Interrupt Enable Bit and Specific Interrupt Flag need to be 1.

   1) Hardware stores the Programm Counter
   2) Set Global Interrupt Enable Bit to 0
   3) Programm Counter is set to the Look-Up-Table
   4) Programm Counter Jumps to ISR
   5) Context is stored
   6) ISR-Code is Executed
   7) Context is restored
   8) Hardware restores the Programm Counter

Exercise 4: Timers and Counters

a) What is a counter? What is a timer?

Solution:
Counter: Hardware unit that counts external events (Rising edges, falling edges, arbitrary edges)
Timer: Special counter that counts clock cycles

b) What components does timer 1 of the ATmega16 have? How are they configured?

Solution:
Counter Register TCNT1 (TCNT1H, TCNT1L)
Compare Register OCR1 (OCR1H, OCR1L)
Input Capture Register ICR1 (ICR1H, ICR1L)
Control Register TCCR1 (TCCR1A, TCCR1B)

c) How is the reading and writing of a 16 bit value made atomic?

Solution:
Parallel reading and writing by Reading the Low-Byte and Writing the High-Byte first, then vice-versa. (However disabling ISR is neccessary)

d) What is a watch dog?

Solution:
A watchdog is a timer that counts from an initial value to zero. When zero is reached, the μC is restarted. In the main loop of the program, the watchdog counter is reset to the initial value.

e) Why might it be necessary to temporarily disable interrupts when reading 16 bit values?

Solution:
Reading 16 bit values requires two cycles (on 8-bit platforms). Interrupts could occur between those two cycles and could corrupt the 16-bit value that is accessed by the main program.

Exercise 5: Analog Devices

a) What analog devices can be found on a ATmega16?

Solution:
4 PWM channels, an 8-channel-10-bit A/D converter (Successive Approximation Converter) and an Analog comparator

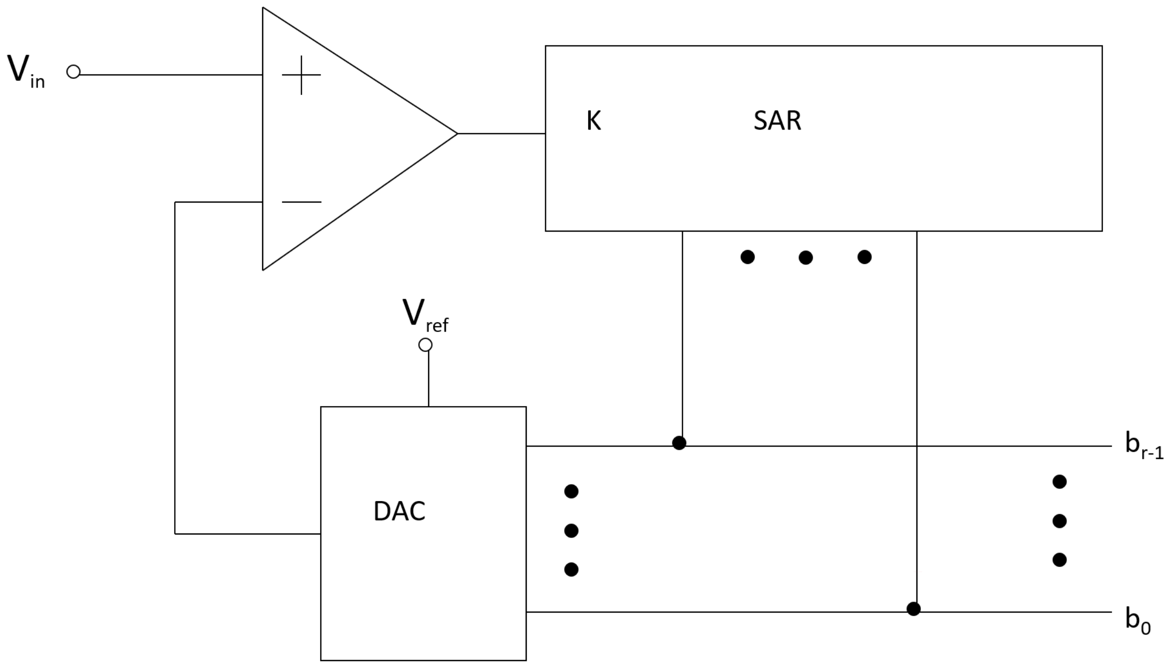
b) What is PWM and how does it work?

Solution:
Pulse width modulation produces a rectangular signal with a configurable frequency and high time. PWM is a hardware feature that usually can produce signals with a much higher frequency than would be possible by producing the signal in software. PWM can be used to reduce the average voltage delivered on a PIN.

The average voltage (also called the value of the signal), can be computed like this: $value = \frac{hightime}{period} \cdot V_{CC}$

c) Sketch a successive approximation converter and explain how it works.

Solution:



A successive approximation converter performs a binary search through all representable signal levels. In each step, the value of one bit of the digital signal level is determined. The successive approximation converter starts with all level bits set to zero. In the first step, the highest bit is set to one. A DAC produces a signal that corresponds to the current "guess". A comparator is used to determine if the signal is greater or smaller than that "guess". If it is greater, the bit is left at one, otherwise it is reset to zero. This process is repeated for the second-highest and then all other bits, until all bits are fixed.

d) Imagine you only have 1 Ohm Resistors available, which cost 10 cents each. What is the minimum achievable cost for a 4Bit R-2R and a 4Bit binary weighted resistor circuit respectively if you can only combine resistors in serial?

Solution:
R-2R: 1,3 Euro (13 resistors)
BWRC: 2,3 Euro (23 resistors)

e) What are the disadvantages of the binary weighted resistor circuit?

Solution:
Many different types resistors or many resistors are needed for BWRC (or many resistors of the same type in series, which is not preferable in practice). This leads to either bad quality of the produced voltage level due to different deviations from the nominal value of the resistances, or to high costs if high-precision resistances are used.