Embedded Systems

- in an operating systems level 3 course it would be remiss not to discuss embedded systems
- an embedded system is typically a low cost, low memory, low power hardware device which is controlled by a microprocessor
- typically the microprocessor has all the flash memory, ram, i/o all on board
  - for example the AVR series of microprocessors from Atmel
  - Atmel produce literally hundreds of microprocessors of different specifications
  - you need to choose the correct one!

Atmel ATMega series of microprocessors

- the number of components to make a minimal system is tiny
- these devices are RISC microprocessors employing a Harvard processor architecture
  - gcc supports these devices!
- they are also extremely easy to interface to peripherals
  - A->D, D->A, pwm (servo and motor control) etc
  - multiple hardware timers etc

Small sample of AVR microprocessors and features

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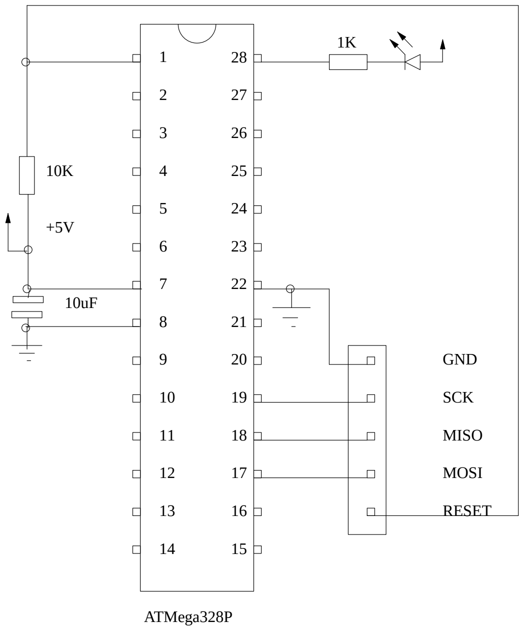
Device Family	Applications	Key Parameters
32-bit AVR UC3	General Purpose	16-512KB Flash 48-144 pins Up to 66 MHZ 1.5 MIPS/MHz
8/16-bit AVR XMEGA	General Purpose	16-384KB Flash 44-100 pins Up to 32 MHz 1.0 MIPS/MHz
8-bit megaAVR	General Purpose	4-256KB Flash 28-100-pins Up to 20 MHz 1.0 MIPS/MHz
8-bit tinyAVR	Small space	0.7V operation 0.5 - 8KB Flash 6-32 pins Up to 20MHz 1.0 MIPS/MHz

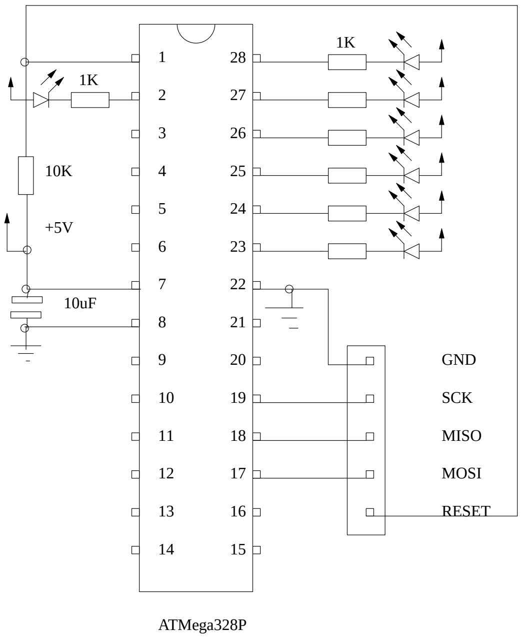
Atmel 328p

- is an 8-bit AVR RISC-based microcontroller (some of its features include):
  - 32KB flash memory with read-while-write capabilities
  - 1024B EEPROM, 2KB SRAM
- 23 general purpose I/O lines
  - 32 general purpose working registers
  - three flexible timer/counters with compare modes
  - internal/external interrupts, a 6-channel 10-bit A/D converter
  - programmable watchdog timer with internal oscillator
- many features omitted for sake of brevity

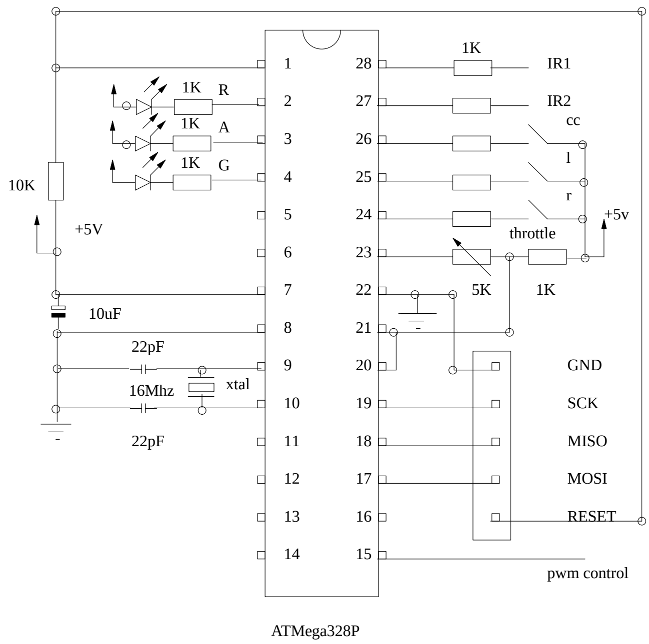
Flashing LED with ATMega328p

- 

Electric die with ATMega328p

- 

E-bike cruise controller with ATMega328p

- 

Flashing LED software

- system contains a minimal device driver!

- ```
static void turn (int on)
{
  if (on)
    (* turn LED on *)
    asm volatile ("cbi 0x15, 5");
  else
    (* turn LED off *)
    asm volatile ("sbi 0x15, 5");
}
```
```

Flashing LED software

```
/*
 * initLed - initialize pin 0 as an output
 */

static void initLed (void)
{
   asm volatile ("sbi 0x14, 5");
}
```


Flashing LED software

```
#define Delay 200

main (void)
{
   int i, j;

   initLed();
   turn(FALSE);
   while (TRUE) {
      for (i=0; i++; i<Delay)
         for (j=0; j++; j<Delay)
            asm volatile ("nop");
      turn(TRUE);
      for (i=0; i++; i<Delay)
         for (j=0; j++; j<Delay)
            asm volatile ("nop");
      turn(FALSE);
   }
}
```


Cruise controller

- cruise controller for an E-bike
- inputs: 5K pot (throttle), left/right break switch
  - two infared switches which measure rotation speed of the motor and bicycle wheel
- bicycle wheel speed is dependent upon throttle position
  - if the bicycle wheel rotation >= throttle position then motor is off
  - cruise controller can also dampen acceleration
  - not apply any motor until the bicycle is moving at say 3mph
  - regulate speed to a max of 15mph

Servo specifications

- typically a servo has three wires: red, black, white
  - black (GND)
  - red (+4.8v..6.0v)
  - white signal
- signal is normally a square wave with a period of
  - 1.0ms full left
  - 1.5ms middle
  - 2.0ms full right

Configuring the ATMega8/168/328 to control a Servo

- use the phase and frequency correct mode of the on chip timer
  - to generate square wave of period between 1.0ms..2.0ms
  - frequencies of between 1000Hz..500Hz

Motor speed test code

```
#define F_CPU 16000000UL

#include <inttypes.h>
#include <avr/io.h>
#include <avr/pgmspace.h>
#include <avr/eeprom.h>
#include <avr/interrupt.h>
#include <stdio.h>
#include <util/delay.h>
```


Motor speed test code

```
#define ePRESCALER8

#if defined(ePRESCALER8)
#   define eICR1value 39936
#   define ePRESCALEBITS  (_BV(CS11))
#   define eLOW    2048
#   define eHIGH   3968
#   define eDELAYms   3
#endif
```


Motor speed test code

```
#if defined(ePRESCALER256)
#   define eICR1value 1248
#   define ePRESCALEBITS  (_BV(CS12))
#   define eLOW      64
#   define eHIGH    124
#   define eDELAYms 100
#endif

#if defined(ePRESCALER1024)
#   define eICR1value 1248*4
#   define ePRESCALEBITS  (_BV(CS10) | _BV(CS12))
#   define eLOW      16
/* not a good choice as eHIGH is not exact,
 * 124/4 is not an integer value
 */
#   define eHIGH     31
#   define eDELAYms 400
#endif
```

Initialise the PWM output devices

```
/*
 * initServo - initialises timer 1 for fast PWM operation
 *             servo is enabled on B1.
 */

void initServo (void)
{
  /* initialize TMR1 (PWM) */
  /* clear on compare, fast PWM, TOP=ICR1 (WGM13/WGM12 in
  TCCR1A = _BV(COM1A1) | _BV(COM1B1) | _BV(WGM11);
  /* set prescaler value */
  TCCR1B = _BV(WGM12) | _BV(WGM13) | ePRESCALEBITS;
  ICR1 = eICR1value;
  OCR1A = -1;  /* off */
  OCR1B = -1;  /* off */
  DDRB |= _BV(1) | _BV(2);  /* output on PB1 and PB2 */
}
```


Main device driver :-)

```
/*
 *  set_servo1 - sets the pwm length for servo1.
 *               Value should be between eLOW..eHIGH
 */

void inline set_servo1 (int pwm)
{
  OCR1A = pwm;
}

/*
 *  set_servo2 - sets the pwm length for servo1.
 *               Value should be between eLOW..eHIGH
 */

void inline set_servo2 (int pwm)
{
  OCR1B = pwm;
}
```


Motor test code ramp up and down

```
main ()
{
  int i;
  initServo ();

  while (TRUE) {
    for (i=eLOW; i<=eHIGH; i++) {
      _delay_ms(eDELAYms);
      set_servo1 (i);
    }
    for (i=eHIGH; i>=eLOW; i--) {
      _delay_ms(eDELAYms);
      set_servo1 (i);
    }
  }
}
```


Compiling

```
$ avr-gcc -mmcu=atmega168 pwmtest.c -o cflashled.elf
```

Linking

```
$ avr-objcopy -R .eeprom -O ihex cflashled.elf cflashled.
```


Loading the code

- note that the actual device is the ATMega328p
  - we compiled using the `-mmcu=atmega168` switch on `gcc` since `gcc-4.1.2` does not know about the newer ATMega328p
  - fortunately they are upward compatible
  - but the top 16K flash ram will not be used
  - should really use use gcc >=4.6.x

```
$ sudo avrdude -p m328p -U lfuse:w:0xff:m -U hfuse:w:0xd9
     -U efuse:w:0x07:m -c stk500v2 -e -v -U flash:w:cflas
```


Simulation of the E-bike transmission under computer cruise control

- ⟨http://floppsie.comp.glam.ac.uk/download/avi/3-low-motor.ogv⟩