Introduction to Microcontrollers: Arduino Tutorial

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OUTLINE

➢ Introduction
➢ Microcontrollers Architecture
  ➢ Arduino environment
    ➢ Arduino boards
    ➢ Sensors interface
    ➢ Application control
    ➢ Arduino UNO board
    ➢ Coding example
    ➢ Applications
➢ Bibliography
Introduction

What is a microcontroller?

❖ Small computers integrated in a single chip:
  ▪ CPU, RAM, EEPROM and other Peripherals in the same package.

❖ Excellent for embedded applications;
❖ Low cost and low power consumption;
  (ATMEGA328P ~ 1.5 $)
❖ Can work up to tens of MHz as clock frequency;
  ▪ Can work with low frequency also, few MHz.
❖ Standalone devices;
  ▪ most of them only need power and a clock source to run.
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Introduction

What are they used for?

❖ Data control;
❖ Data Acquisition Systems;
❖ Power control and monitoring;
❖ Motor control applications;
❖ Smartphones;
❖ Automotive industry;
❖ Nuclear instrumentation;
❖ Space applications.

- In general are used in applications where high processing resources are not required, hence a general purpose microcontroller is considered suitable due to the low power consumption and without any peripheral and external memories;
- Also, the cost may be an important factor.

https://atmelcorporation.wordpress.com/tag/avr-microcontrollers/
Introduction

Famous microcontroller manufacturers:

- Microchip;
- Atmel (now is part of Microchip);
- Intel;
- Analog Devices;
- MAXIM Integrated;
- Renesas Electronics.

A detailed list can be found at:
http://embedeo.org/microcontroller_manufacturers/
Microcontrollers Architecture

I/O PERIPHERALS
- A/D CONVERTER
- I/O PINS
- D/A CONVERTER
- PWM BLOCKS

CPU
- MEMORY
- RAM
- EEPROM
- CLOCK SOURCE
- WATCHDOG TIMER

COMMUNICATION INTERFACES
- USART
- SPI
- I2C
- USB
- WI-FI

Simplified Architecture

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Arduino environment

- Open source-source electronics development board, based on easy-to-use hardware and software interface;
- Very easy to use and its has a broad range of libraries and example codes;
- Arduino language is merely C/C++;
- It has embedded an U(S)ART monitor in order to check the communication with microcontroller;
- Using Processing software (embedded in the latest Arduino compiler version) data can be displayed, GUIs can be made;
- More at: https://www.arduino.cc/.
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Arduino Boards

- Arduino UNO
- Arduino Mega 2560
- Arduino Due
- Arduino BT
- Arduino LilyPad
- Arduino NANO
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**Arduino UNO Board**

- **Digital I/O PINS**
  - Pulse Width Modulation (PWM) included (~)
  - Direct connection to the hardware UART block

- **Hardware SPI block:**
  - 13 => SCLK
  - 12 => MISO
  - 11 => MOSI
  - 10 => SS

- **USB Port**

- **USB-UART bridge**

- **Input voltage**
  - (7-12 V recommended)

- **16 MHz quartz oscillator**

- **Power Supply Distribution**
  - (can be used to power up peripherals)

- **Analog inputs**
  - 10-bit within the range 0 – Vref (max. 5 V)

- **Hardware I2C**
  - A4 => SDA
  - A5 => SCL

- **ATMEGA328P Microcontroller**

- **In circuit Serial programming**

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Sensor interface

Analog or digital?

➢ Sensor: an analog/digital device which converts the physical quantity into an electrical signal;
➢ All related physical quantities are related to ANALOG interface, where the quantity can take any value between the hardware minimum and maximum values;
➢ DIGITAL interface is used to describe the quantity which has only 2 levels, 1 or 0 logic.

Sine waves are analog, because the amplitude can vary between minimum and a maximum value.

Square waves are digital, because the amplitude can vary only between 2 values, 0 or 1 logic.
Sensor interface
Classification

- AIR QUALITY SENSORS
- LIGHT SENSORS
- TEMPERATURE SENSORS
- HUMIDITY SENSORS
- BAROMETRIC SENSORS
- HEALTH CARE SENSORS
- PROXIMITY SENSORS
- ACCOUSTIC SENSORS
- VOLTAGE & CURRENT SENSORS
- MEMS SENSORS

MEMS => Microelectromechanical systems.
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Application control

- COMPLEX DAQ SYSTEMS
- RELAYS
- ROBOTS
- SMART HOUSE
- TRANSISTORS,
- MOTORS
- AUTOVEHICLES
- DRONS & UAV (UNMANNED AERIAL VEHICLE)
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Arduino UNO Board

- 8-bit RISC architecture microcontroller;
- 32 KB In-System Self-Programmable Flash program memory;
- 1 KB EEPROM, 2 KB SRAM;
- 6 PWM channels;
- 8 x 10-bit resolution ADC inputs;
- UART, SPI, I2C;
- On chip analog comparator;
- 3 Timers: 2 x 8-bit and 1 x 16-bit;
- Up to 23 Programmable I/O lines;
- Write/erase cycles: Up to 10,000 for Flash/ 100,000 for EEPROM;
- Speed Grade: 0 - 4 MHz @ 1.8 - 5.5 V, 0 – 10 MHz @ 2.7 – 5.5 V, 0 – 20 MHz @ 4.5 – 5.5 V;
- Power consumption: 0.2 mA in Active Mode @ 1 MHz, 1.8 V and 25 °C.

Full datasheet
Arduino UNO Board

ATMEGA328P Architecture

Full datasheet
General purpose Input/Output (GPIO)

- Are the interface of logic software with external hardware;
- Can be programmable as Input or Output;
- Can read or write digital signals;
- logic 0 = 0 V and logic 1 = Vcc;
- Are controller by 3 registers:
  - DDR (Data Direction Register);
  - PORT (load data when the pin is set as output);
  - PIN (load data when the pin is set as input).
Timers / Counters

➢ Specific internal registers that increment data and be triggered by:
   ❖ A clock source : Timer;
   ❖ An external event : Counter.

Utilities:
❖ Time domain measurements;
❖ Create PWM waveforms.

HC-SR04 ultrasonic distance sensor, it returns the distance measurement based on echo time of an ultrasonic pulse.
Interrupts

- Are used to break a routine of an program or entire program flow in order to handle a specific event.

- Are triggered by:
  - Input pin state change (rise/fall/toggle);
  - Serial communication (USART, SPI, I2C);
  - ADC state registers;
  - Analog comparator;
  - Timers or Counters.

ISR => Interrupt Service Routine
Internal Analog Comparator

- **ANI0** ⇒ V1;
- **ANI1** ⇒ V2;
- Its output value is located in the ACSR register, named ACO bit;
- V2 can be tied to the output of the ADC multiplexer, hence can be tied to any of the analog inputs;
- As a general information is good to know that any comparator is an 1-bit ADC;

Utilities:
- Compare 2 analog voltages;
- Trigger a Timer/Counter1 Input Capture function;
- Trigger an Interrupt (rise, fall, toggle).

ACO => Analog Comparator Output;
ACSR => Analog Comparator and Status Register.

More information at page 234
Analog to Digital Converter (ADC)

- 10-bit resolution => 0 – Vref => 0-1023;
- **Successive-approximation (SAR) architecture**;
- 1 ADC with up to 8 multiplexed input channels => they share the sampling rate;
- one channel is dedicated for internal temperature monitoring;
- Vref can be:
  - Vcc from power source; (not very recommended because the power supply can be noisy)
  - 1.1 V internal voltage reference;
  - External, from an external voltage reference.

More about ADC
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Pulse width modulation (PWM)

- A square signal can be generated with a variable duty cycle;
- ATMEGA328P has six 8-bit PWM channels;
- Can be used for:
  - To control DC-DC converters;
  - To control the speed for motors;
  - To control the luminosity of LEDs or lamps;
  - To generate an analog voltage directly proportional with duty cycle value.

\[
\text{Duty cycle} = \frac{\text{Ton}}{\text{T}}
\]
Pulse width modulation (PWM)

- PWM can be used to generate a stable DC signal if its passed to a low pass filter, RC passive integrator;
- An 8 bit PWM signal will emulate an 8-bit DAC (Digital to Analog Converter).
Communication interfaces

~USART~

➢ Stands for Universal Synchronous/Asynchronous Receiver/Transmitter; (one to one communication)
➢ Most common is used UART => Universal Asynchronous Receiver/Transmitter;
➢ The data transfer speed is defined as baud rate (bit rate);
➢ Normally is defines as:
  ❖ One start bit;
  ❖ 8 data bits;
  ❖ 1 stop bit.

More at:
http://www.circuitbasics.com/basics-uart-communication/
Communication interfaces

~SPI~

➢ Stands for Serial Peripheral Interface, and its describes a serial communication used in embedded systems;
➢ Support multiple slaves communications, but only one at time;
➢ Can perform full duplex;
➢ One to many communication.

SCLK => Serial Clock;
MOSI => Master Output Slave Input;
MISO => Master Input Slave Output;
SS => Select Slave.

Read more about SPI
Communication interfaces

~I2C~

➢ Stands for Inter-Integrated Circuit, also know as Two Wire Interface (TWI);
➢ Serial protocol which allows multiples masters and slaves on the same bus, up to 128; (many to many communication)
➢ Normally each device has an unique 7-bit or 10-bit address in the I2C bus;
➢ Being used in variety of digital sensors, can reach speeds up to 400 kbps. (Arduino UNO)

SCL=> Serial Clock Line;
SDA=>Serial Data Line.

Read more about I2C
Coding example
~blinking a led~

➢ First of all, the latest version of Arduino compiler must be installed from: https://www.arduino.cc/ ;
➢ Run the compiler and go to File=>Examples=>Basics=>Blink ;
➢ A new windows with the related software should appear on your screen;
➢ Compile the code and upload it on the board; (The board new to be connected to the PC already)
➢ Change the delay value, and observe what happen.
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Coding example
~blinking a led~

Delay value = 1000 ms

Simulation was made with the online simulator available at: https://circuits.io
Coding example

~blinking a led~

Delay value = 250 ms

Simulation was made with the online simulator available at: https://circuits.io
Applications

➢ Temperature & Humidity sensor readout;
➢ Proximity sensors readout => ultrasonic radar;
➢ Leds control;
➢ Light sensor application;
➢ Wearable multi-sensor data acquisition system.

❖ Readout will be made with the Arduino UNO board and data will be send via UART or Bluetooth to an LabVIEW GUI (Graphical User Interface).
Temperature & Humidity Sensor Readout

- Based on low cost DHT11 sensor with 1 wire interface;
- Sampling rate need to be lower than 1 Hz (once every second);
- Data is acquired and displayed with a LabVIEW GUI over UART interface;
Ultrasonic Radar

➢ Provide good measurement between 2 and 400 cm;
➢ Easy to interface with any microcontroller;
➢ Widely used in robots and system were distance to a specific object is needed to be know.
➢ A good reference article

Datasheet
Leds Control

- Various Leds turned on and off with Arduino UNO board using commands received over UART from a LabVIEW GUI;
- Their luminosity will be also controller using PWM technique by calling the `analogWrite` function;
- ASCII commands are used to control the Arduino board.
Light sensor application

- The total luminous flux incident on a surface can be measured using light sensors, **illuminance**, expressed in SI unit as lux (lx);
- Ambient Light sensor TEMT6000 is used;
- TEMT6000 is a NPN phototransistor sensitive to the visible spectrum;
- The collector light current feed a 10 KΩ load resistor;
- Voltage drop across resistor can be transformed using a formula from datasheet.
Smart, low power, wearable multi-sensor data acquisition system for environmental monitoring

➢ Full article at: https://doi.org/10.1109/ATEE.2017.7905059
1. https://www.arduino.cc/
2. https://forum.arduino.cc/