

# Embedded Systems Development using the Arduino Platform

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ARTESIS PLANTIJN  
HOGESCHOOL ANTWERPEN

# Outline

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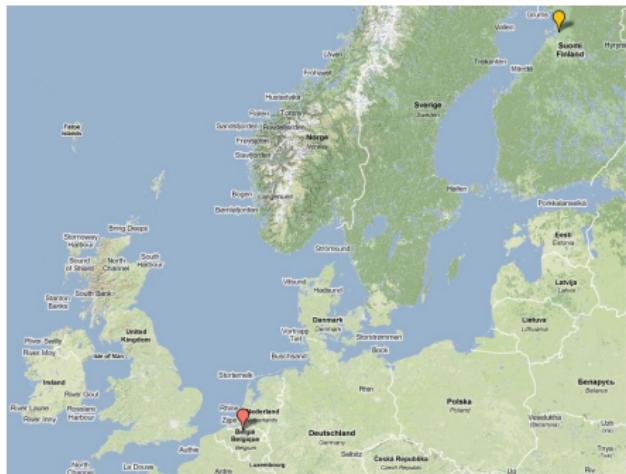
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# Where?



## Population:

- ▶ Belgium: 10.8 million
- ▶ Antwerp: 461.000

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## Port of Antwerp

- ▶ 2nd largest of Europe
- ▶ Inland connection to central Europe

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# Who are we?

Artesis Plantijn University College of  
Antwerp

- ▶ 6 Departments (faculties)
- ▶ 6 locations in and around the city
- ▶ Dept. of Science and Technology  
(± 1500 students)



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# Who are we?

Artesis Plantijn University College of Antwerp

- ▶ 6 Departments (faculties)
- ▶ 6 locations in and around the city
- ▶ Dept. of Science and Technology ( $\pm$  1500 students)
- ▶ Bachelor degree programs:
  - ▶ Electronics-ICT
  - ▶ Electromechanics
  - ▶ Chemical and laboratory science
  - ▶ Graphical and digital media
  - ▶ Real-estate
  - ▶ Energy and security



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# Who are we?

Electronics-ICT

<http://www.artesis.be/technologie>

- ▶ 7 lecturers
- ▶ ± 110 students (3 year curriculum)

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# Who are we?

## Electronics-ICT

<http://www.artesis.be/technologie>

- ▶ 7 lecturers
- ▶ ± 110 students (3 year curriculum)

Main courses for final year students:

- ▶ Smart Objects and Wireless Sensor Network applications
- ▶ Software development for multimedia systems
- ▶ Network security & network attacks
- ▶ Digital signal processing: audio applications

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# Who am I (*at work*)

- ▶ Graduated at University College Antwerp, 2006 (M.Sc.)
  - ▶ Thesis: Design of a H.264 AVC video streaming model for simulation in OPNET Modeler
  - ▶ Erasmus student Universitat Ramon Llull, Barcelona

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# Who am I (*at work*)

- ▶ Graduated at University College Antwerp, 2006 (M.Sc.)
  - ▶ Thesis: Design of a H.264 AVC video streaming model for simulation in OPNET Modeler
  - ▶ Erasmus student Universitat Ramon Llull, Barcelona
- ▶ University Antwerp (2006-2008)
  - ▶ Researcher: Network simulations: WSN & InfiniBand
  - ▶ Dept. Mathematics & Computer Science, Performance Analysis of Telecommunication Systems Research Group (PATS)

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# Who am I (*at work*)

- ▶ Artesis Plantijn University College Antwerp (2006 - present)
  - ▶ Researcher: Wireless Sensor Networks, network simulations
  - ▶ Teaching Assistant: Wireless Sensor Networks, network simulations, multimediatools
  - ▶ Lecturer/researcher: Digital electronics, embedded systems

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# Who am I (*online*)<sup>1</sup>

- ▶ Development of open source Arduino libraries:  
sensors, communication, motor control,...  
(currently 15+ projects)
  - ▶ Github: <http://github.com/jeroendoggen>
- ▶ Tools for Arduino development: Unit test  
automation tool
- ▶ L<sup>A</sup>T<sub>E</sub>X handouts builder for course handouts
- ▶ Blackboard Analysis Tool for grading student  
assignments
- ▶ Technology related blogging

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<sup>1</sup>[about.me/jeroendoggen](http://about.me/jeroendoggen)

# Who am I? (current studies)

- ▶ Bachelor natural sciences, Open University Netherlands (2012-present)
  - ▶ Current courses: energy analysis, evolution theory, fysiology

**Open Universiteit**  
[www.ou.nl](http://www.ou.nl)



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# What are Embedded Systems?

- ▶ A computer system, designed for specific control functions, that is embedded in a device.



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# What are Embedded Systems?

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# What are Embedded Systems?

- ▶ A computer system, designed for specific control functions, that is embedded in a device.
- ▶ Dedicated to handle a particular task.
- ▶ They are optimised:



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# What are Embedded Systems?

- ▶ A computer system, designed for specific control functions, that is embedded in a device.
- ▶ Dedicated to handle a particular task.
- ▶ They are optimised:
  - ▶ Reduce the size and cost



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  - ▶ Increase the reliability and performance



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  - ▶ Increase the reliability and performance
- ▶ Multidisciplinary design



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- ▶ Multidisciplinary design
  - ▶ Hardware: electronics, usability, visual, tactile



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  - ▶ Hardware: electronics, usability, visual, tactile
  - ▶ Communication: wired, wireless
  - ▶ Software: embedded, server



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# Arduino Development Platform

- ▶ The Arduino development platform allow designers to develop electronic prototypes.



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# Arduino Development Platform

- ▶ The Arduino development platform allow designers to develop electronic prototypes.
- ▶ The platform has gained increased popularity over the last years (since 2005).



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# Arduino Development Platform

- ▶ The Arduino development platform allow designers to develop electronic prototypes.
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- ▶ The open-source community has 70000 registered users and an abundance of user submitted libraries.



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- ▶ Ease of use is the main selling point.



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- ▶ Ease of use is the main selling point.
  - ▶ Connect the hardware



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  - ▶ Connect the hardware
  - ▶ Download the software



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- ▶ Ease of use is the main selling point.
  - ▶ Connect the hardware
  - ▶ Download the software
  - ▶ It just works™



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# Arduino Development Environment (IDE)



The screenshot shows the Arduino IDE interface with the title bar "Blink | Arduino 1.0". The menu bar includes File, Edit, Sketch, Tools, and Help. Below the menu is a toolbar with icons for Open, Save, Print, and others. The main window displays the "Blink" sketch. The code is as follows:

```
/*
 * Blink
 * Turns on an LED on for one second, then off for one second, repeating.
 * This example code is in the public domain.
 */
void setup() {
    // initialize the digital pin as an output.
    // Pin 13 has an LED connected on most Arduino boards:
    pinMode(13, OUTPUT);
}

void loop() {
    digitalWrite(13, HIGH);      // set the LED on
    delay(1000);                // wait for a second
    digitalWrite(13, LOW);       // set the LED off
    delay(1000);                // wait for a second
}
```

The status bar at the bottom indicates "1" and "Arduino Duemilanove or ATmega328 on /dev/ttyUSB0".

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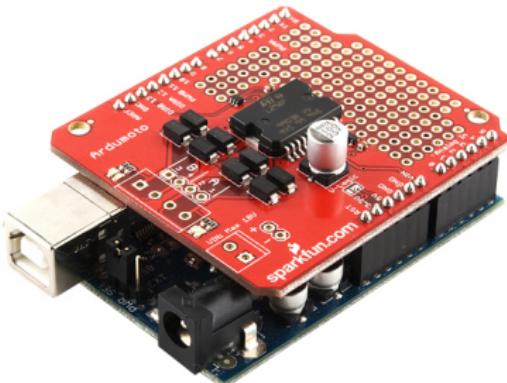
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# Motor Control Shield

- ▶ Shield: click-on modules with standardised pin locations
- ▶ Enables the development of motor controlled “things”



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# Motor Shield Applications



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# Motor Shield Applications

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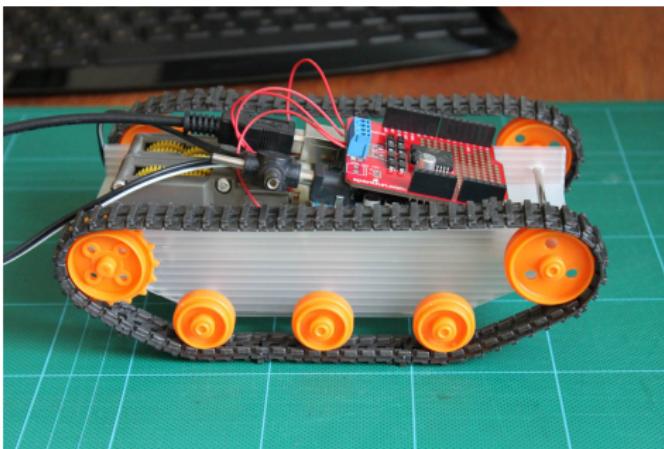
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# Sound and Speech Synthesizer



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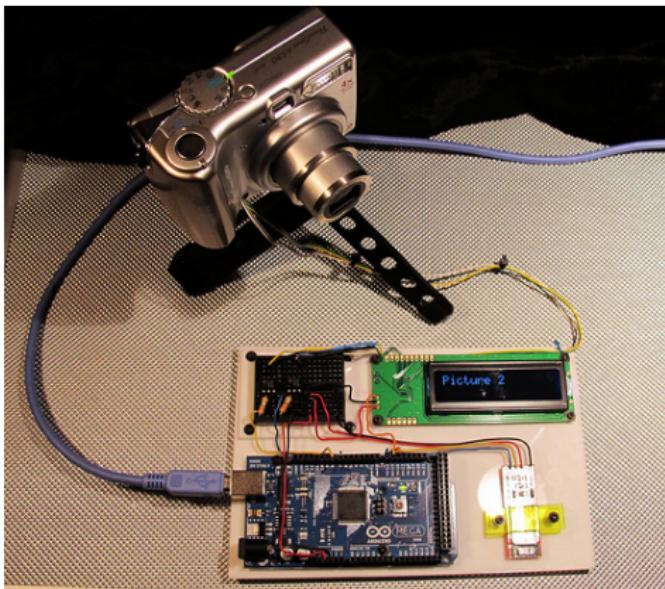
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# Interfacing with Consumer Electronics



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# Documenting Your Projects

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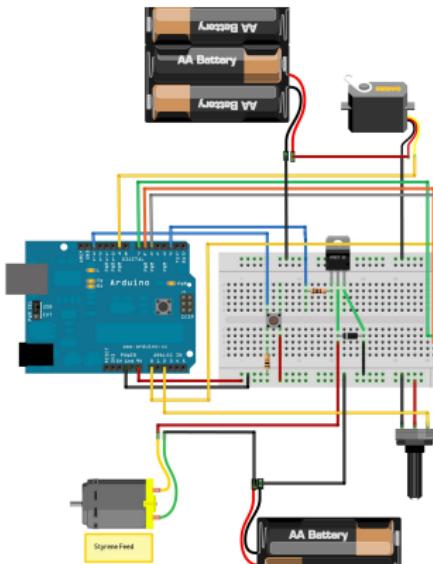
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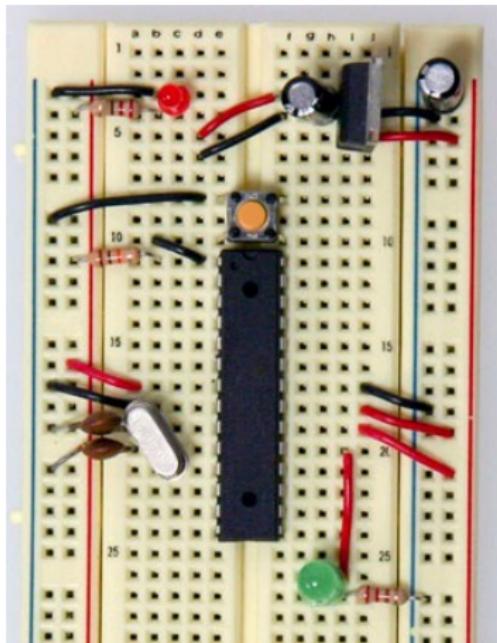
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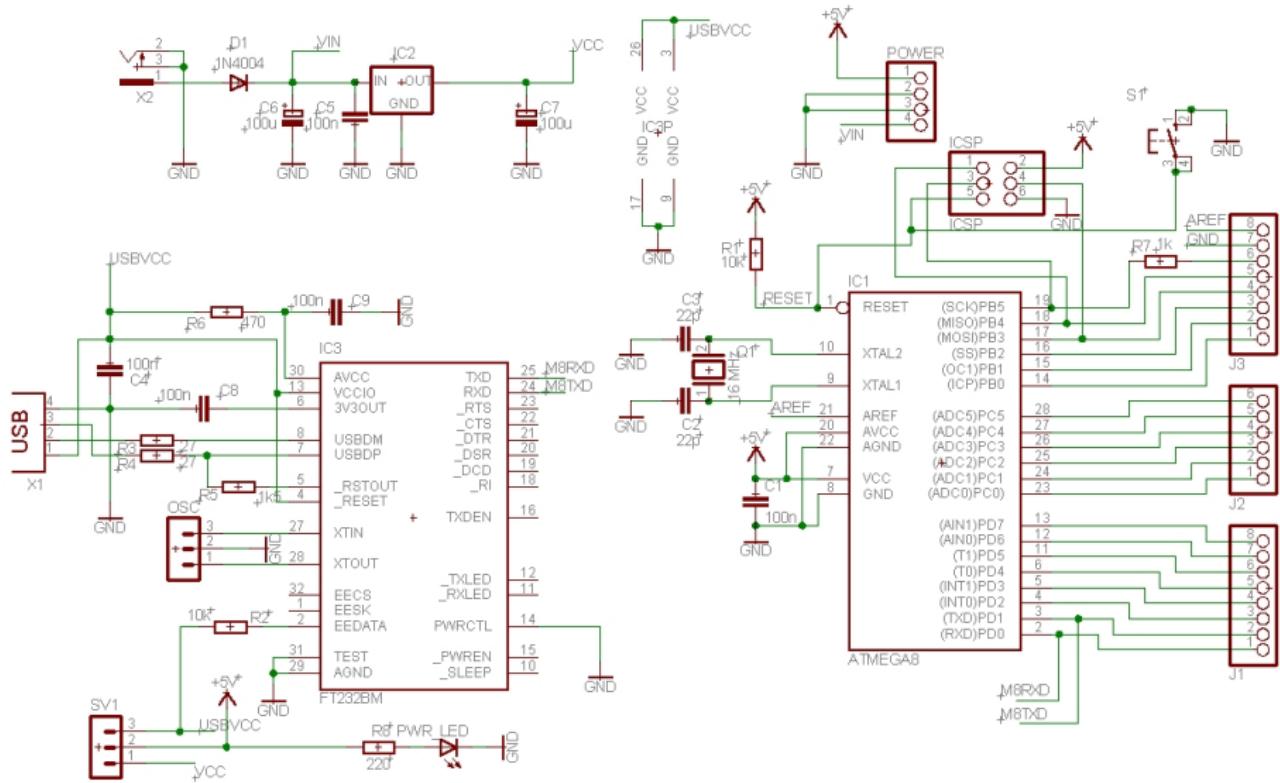
# Components of the Arduino



- ATMega168/328
- 16MHz crystal/filtering capacitors
- Onboard power regulators
- FTDI USB <-> Serial Chip
- Hardware



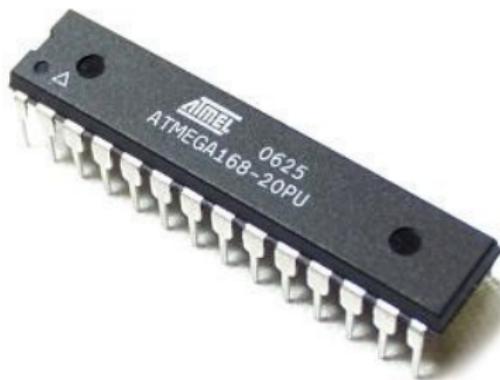
# Schematic





## Necessary parts for any circuit

- ATMega168/328
- The ‘brains’ of the Arduino
- Program is loaded onto the chip
- Runs main loop until power is removed
- That’s it! All other parts are optional!



(C) HVWTech, 2008



## Optional parts: Timing

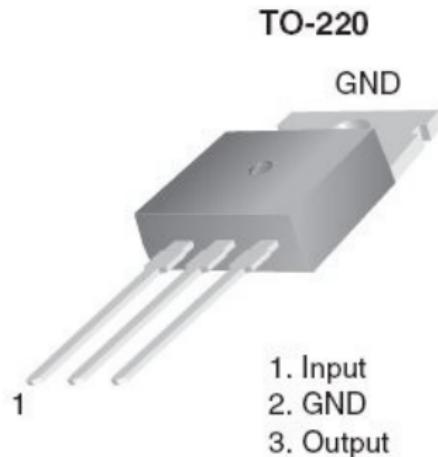
- 16Mhz Crystal
- The ‘heartbeat’ of the ATMega chip
- Speed of crystal determines chip speed
- Possible to over/underclock depending on application
- ATMega series has onboard oscillator; less precise



# Power Supply



- 5 Volt and 3.3 Volt Regulators
- Filtering capacitors
- Automatic switching between external and USB Power
- Leave it out if you have a filtered 5 Volt power supply



## FTDI USB Chip



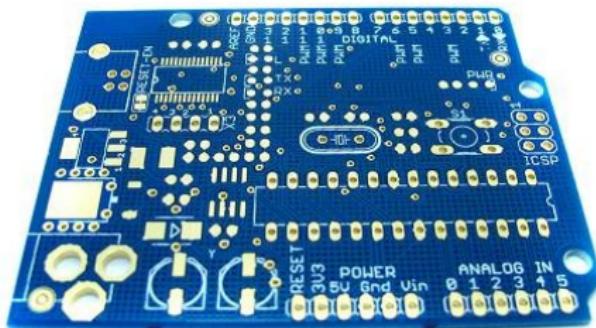
- Allows your Arduino to communicate with your computer over a simple USB link
- Abstraction
- Only necessary for communicating with USB



# Hardware



- Circuit Board
- Headers
- USB port
- Sockets
- All optional, use them if you need them



# Microcontroller Architecture

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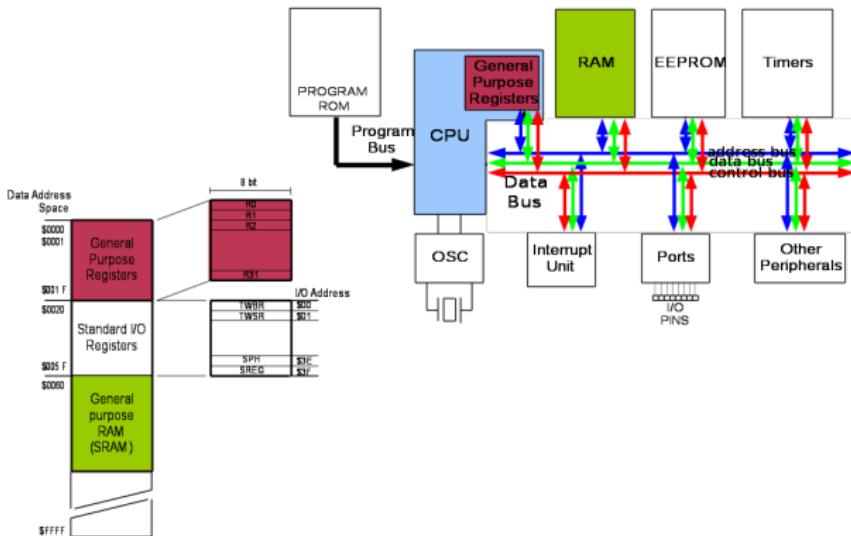
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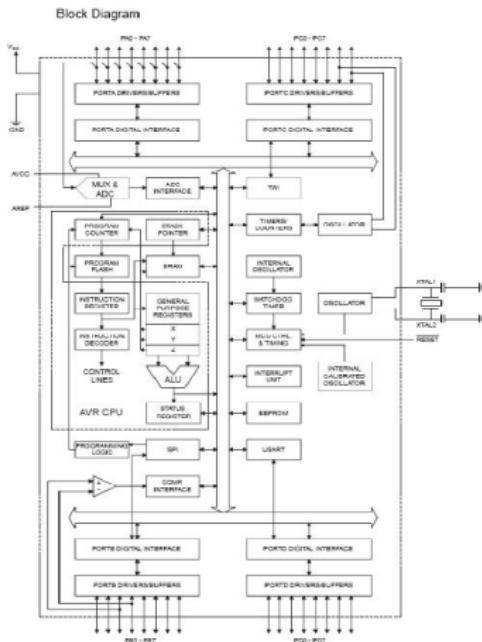
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# Arduino based Smart Objects<sup>2</sup>

- We developed a wireless sensor module based on the Arduino development board.



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<sup>2</sup>Doggen J., Neefs J., Brands E., Peeters T., Bracke J., Smets M., Van der Schueren F.: "Smart Objects for Human Computer Interaction, Experimental Study," ECUMICT, European Conference on the Use of Modern Information and Communication Technologies, Ghent, March 2012.

# Arduino based Smart Objects<sup>2</sup>

- ▶ We developed a wireless sensor module based on the Arduino development board.
- ▶ We use the “smart dice” to control computer applications.



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# Arduino based Smart Objects<sup>2</sup>

- ▶ We developed a wireless sensor module based on the Arduino development board.
- ▶ We use the “smart dice” to control computer applications.
- ▶ This basic concept can be adapted to implement various sensor based applications.



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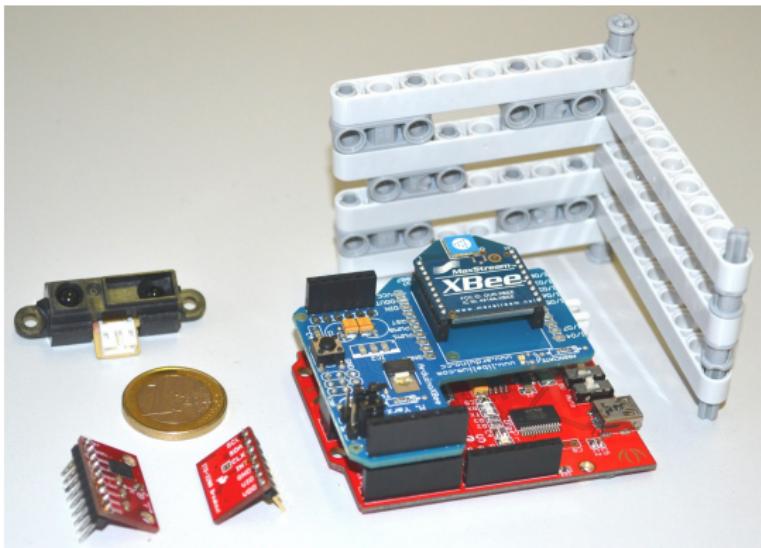
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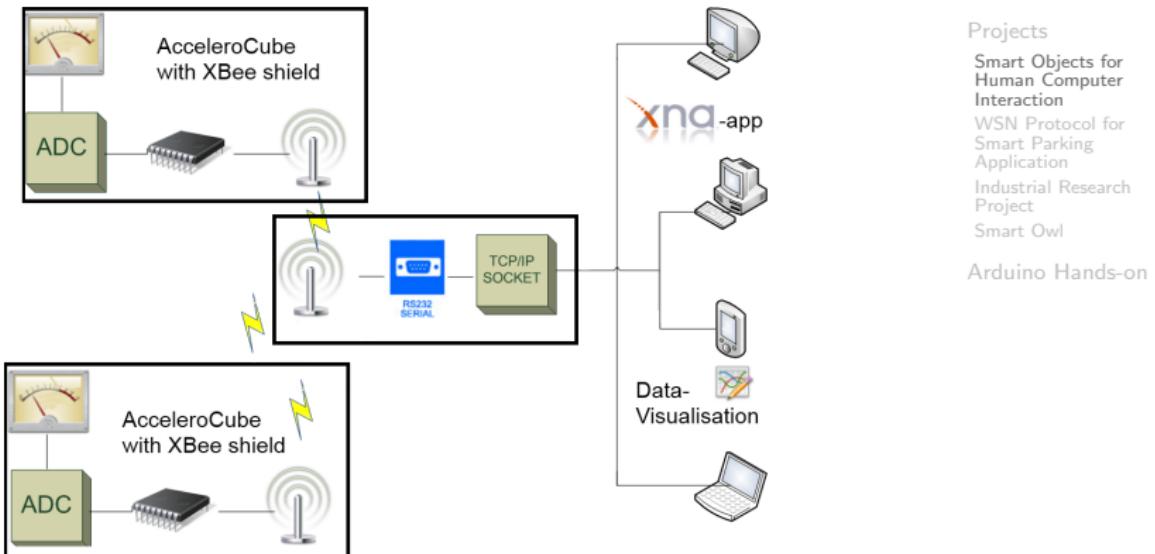
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# System Architecture



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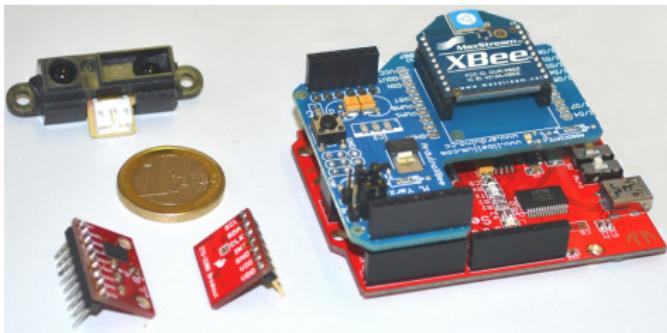
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# Hardware Specifications

- ▶ Seeeduino development board
- ▶ Digi XBee wireless interface
- ▶ Freescale Semiconductor MMA7361 analog accelerometer
- ▶ InvenSense ITG-3200 digital gyroscope
- ▶ Sharp GP2Y0A21YK infra-red distance sensor



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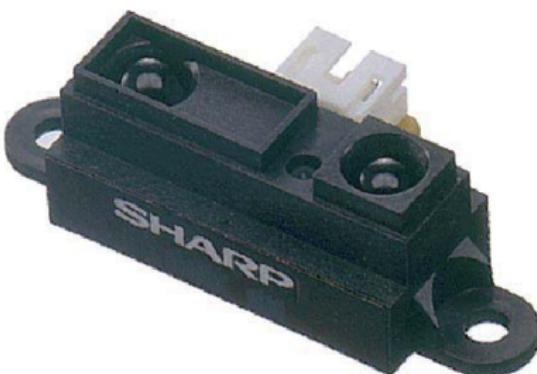
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# Analog Distance Sensor

## Distance Measuring Sensor Unit Analog output type



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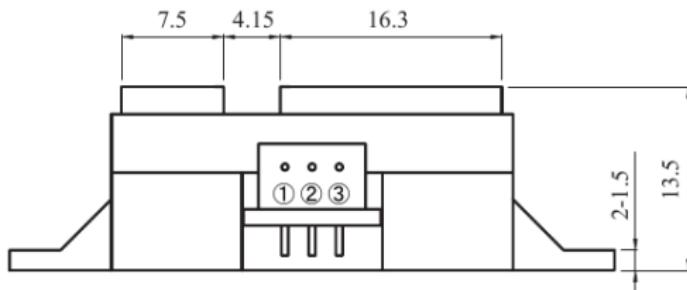
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# Sensor: Physical Properties



Connector signal

	signal name
①	Vo
②	GND
③	Vcc

Connector :  
J.S.T.TRADING COMPANY,LTD,  
S3B-PH

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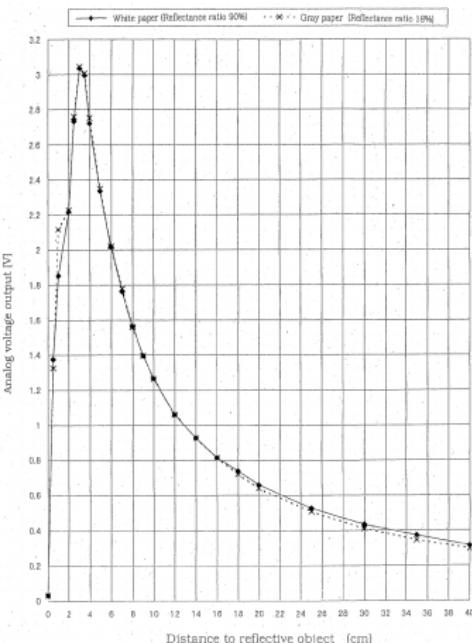
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# Sensor: Output Characteristic



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# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.

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# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.
- ▶ Used Arduino libraries
  - ▶ ITG-3200 Gyro library

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# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.
- ▶ Used Arduino libraries
  - ▶ ITG-3200 Gyro library
- ▶ Developed Arduino libraries
  - ▶ Sharp GP2Y0A21YK infra-red distance sensor
  - ▶ MMA7361 accelerometer
  - ▶ Signal filtering

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# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.
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  - ▶ ITG-3200 Gyro library
- ▶ Developed Arduino libraries
  - ▶ Sharp GP2Y0A21YK infra-red distance sensor
  - ▶ MMA7361 accelerometer
  - ▶ Signal filtering
- ▶ XNA library to connect the module to C# applications

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# Arduino Library: Usage Example

## 1. Include header files

```
#include <DistanceSensor.h>
#include <DistanceGP2Y0A21YK.h>

DistanceGP2Y0A21YK Dist;
int distance;

void setup()
{
>   Serial.begin(9600);
>   Dist.begin(2,3);
}

void loop()
{
>   distance = Dist.getDistanceCentimeter();
>   Serial.print("\nDistance in centimeters: ");
>   Serial.print(distance);
>   delay(500); //make it readable
}
```

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# Arduino Library: Usage Example

1. Include header files
2. Initialise objects and variables

```
#include <DistanceSensor.h>
#include <DistanceGP2Y0A21YK.h>

DistanceGP2Y0A21YK Dist;
int distance;

void setup()
{
>   Serial.begin(9600);
>   Dist.begin(2,3);
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void loop()
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# Arduino Library: Usage Example

1. Include header files
2. Initialise objects and variables
3. setup → configuration

```
#include <DistanceSensor.h>
#include <DistanceGP2Y0A21YK.h>

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# Arduino Library: Usage Example

1. Include header files
2. Initialise objects and variables
3. setup → configuration
4. loop → start example program

```
#include <DistanceSensor.h>
#include <DistanceGP2Y0A21YK.h>

DistanceGP2Y0A21YK Dist;
int distance;

void setup()
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>   Serial.begin(9600);
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# Arduino libraries: usage statistics

- ▶ MMA7361 accelerometer library<sup>3</sup>



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<sup>3</sup><http://code.google.com/p/mma7361-library>

<sup>4</sup><http://code.google.com/p/gp2y0a21yk-library/>

# Arduino libraries: usage statistics

- ▶ MMA7361 accelerometer library<sup>3</sup>



- ▶ Sharp GP2Y0A21YK infrared distance sensor library<sup>4</sup>



- ▶ Total downloads: approx. 2000 & 3000

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<sup>3</sup><http://code.google.com/p/mma7361-library>

<sup>4</sup><http://code.google.com/p/gp2y0a21yk-library/>

# Signal Filtering

- ▶ Many analog sensors have signal differences between individual sensors.
- ▶ Calibration and signal filtering is needed to compensate for these undesirable effects.

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# Signal Filtering

- ▶ Many analog sensors have signal differences between individual sensors.
- ▶ Calibration and signal filtering is needed to compensate for these undesirable effects.
- ▶ We implemented three simple software based filters:
  - ▶ variable-length weighted moving average filter
  - ▶ Bessel low-pass filter
  - ▶ Chebychev low-pass filter
- ▶ The signal filtering library is available online<sup>5</sup>.

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<sup>5</sup><http://code.google.com/p/arduino-signal-filtering-library>

# Software Tools

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# Demo Applications

- ▶ Flight simulator: sensor acts as a joystick
- ▶ Pac-man clone: sensor generates arrow inputs



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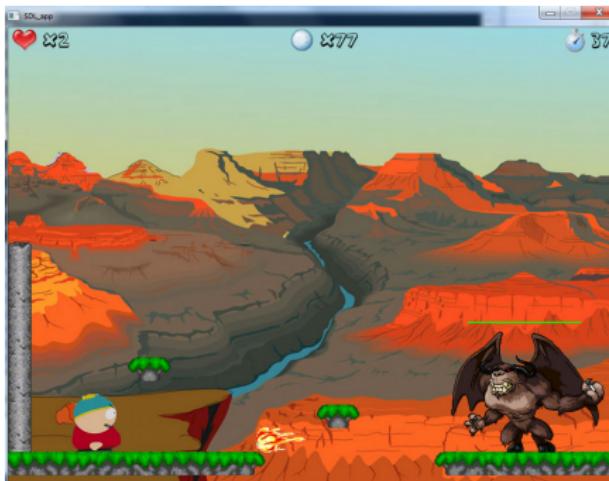
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# Demo Applications

- ▶ 2-D platform game:
  - ▶ Left/right: tilt detection
  - ▶ Jump: upward movement



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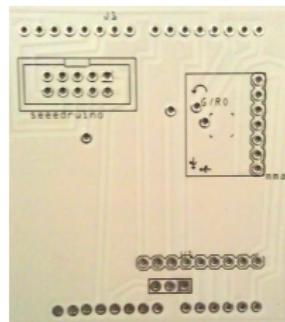
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# Future Work *(as presented in March 2012)*

- ▶ Use mixed RF technologies
  - ▶ Support the more power efficient nRF24 wireless technology



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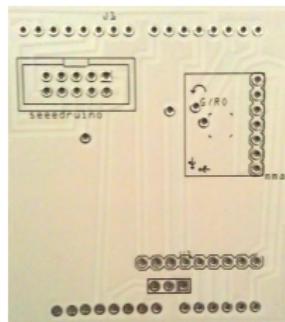
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# Future Work *(as presented in March 2012)*

- ▶ Use mixed RF technologies
  - ▶ Support the more power efficient nRF24 wireless technology
- ▶ Minimise energy consumption



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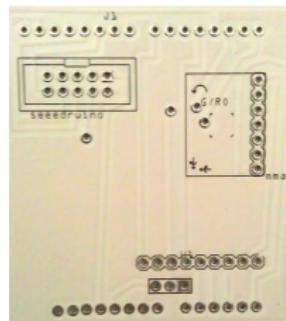
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# Future Work *(as presented in March 2012)*

- ▶ Use mixed RF technologies
  - ▶ Support the more power efficient nRF24 wireless technology
- ▶ Minimise energy consumption
- ▶ Use the module for various student projects:
  - ▶ Development of embedded software
  - ▶ Printed circuit board design
  - ▶ Signal processing applications



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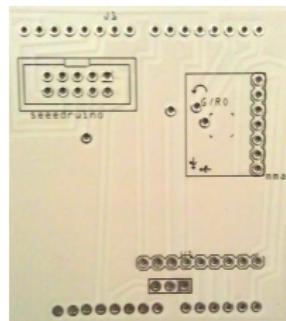
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  - ▶ Support the more power efficient nRF24 wireless technology
- ▶ Minimise energy consumption
- ▶ Use the module for various student projects:
  - ▶ Development of embedded software
  - ▶ Printed circuit board design
  - ▶ Signal processing applications
- ▶ Projects
  - ▶ Development of a city monitoring application
  - ▶ Cooperation with product development department:



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# Conclusions for “Smart Objects Project”

- ▶ We developed an Arduino based “smart cube”, equipped with various sensors.
- ▶ The LGPL licensed Arduino software libraries for these sensors are freely available for download.

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# Conclusions for “Smart Objects Project”

- ▶ We developed an Arduino based “smart cube”, equipped with various sensors.
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# Conclusions for “Smart Objects Project”

- ▶ We developed an Arduino based “smart cube”, equipped with various sensors.
- ▶ The LGPL licensed Arduino software libraries for these sensors are freely available for download.
- ▶ Derivated systems are being used for student projects.
- ▶ We plan to cooperate with third parties by developing similar modules:
  - ▶ Evaluation of the feasibility of industrial applications.
  - ▶ Prototyping tool for product development purposes.

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# We “inspired” Portuguese students



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# Wireless Sensor Networks

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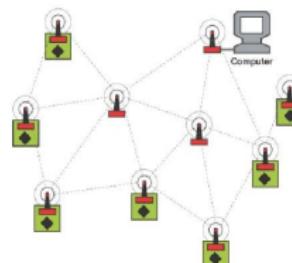
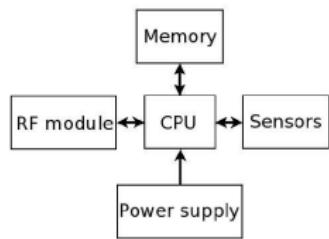
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- A *wireless sensor network* is a set of small autonomous sensor nodes which cooperate to solve a common application using some kind of perception of physical parameters.



# Arduino meets WSN: Why?

- ▶ Typical WSN applications require:
  - ▶ Specialised software knowledge: e.g. TinyOS, Contiki
  - ▶ Specialised hardware: TelosB, Z-Wave, XBee, DASH7



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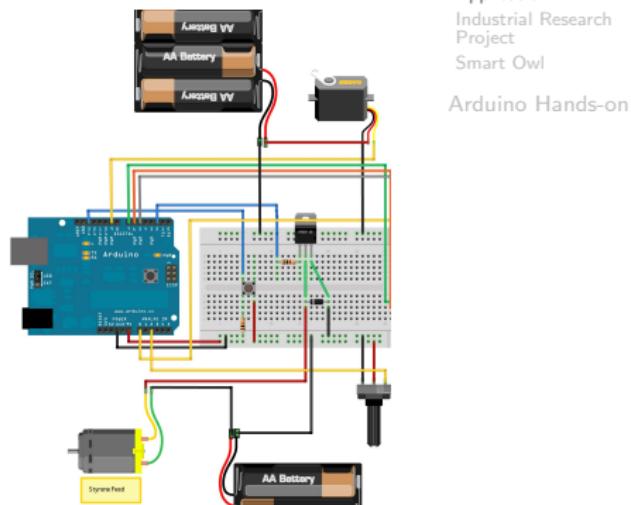
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# Arduino meets WSN: Why?

- ▶ Typical WSN applications require:
  - ▶ Specialised software knowledge: e.g. TinyOS, Contiki
  - ▶ Specialised hardware: TelosB, Z-Wave, XBee, DASH7
- ▶ The Arduino platform provides:
  - ▶ Many well-documented software libraries for hardware interfacing
  - ▶ A big existing user community
  - ▶ Many options to share your own hardware and software



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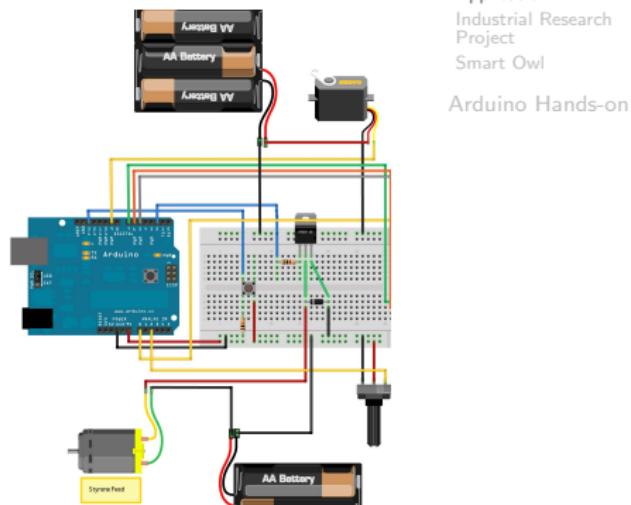
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## Envisioned Application<sup>6</sup>

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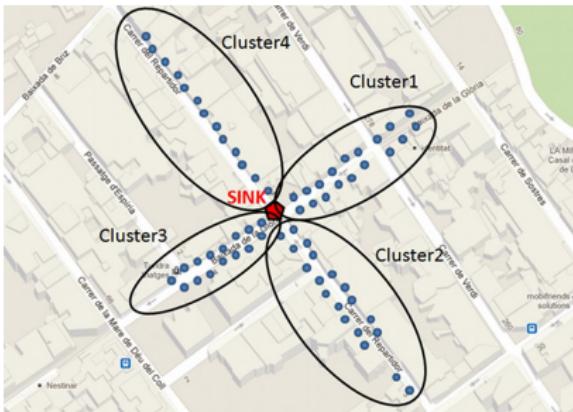
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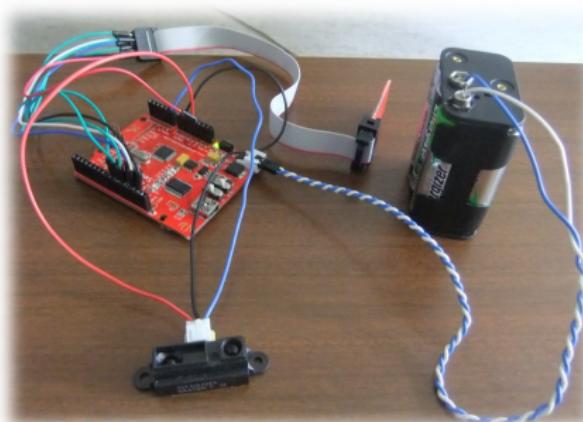
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<sup>6</sup>Ostiz L., Pita C., Doggen J., Dams T., Van Houtven P.: "Wireless Sensor Network Protocol for Smart Parking Application, Experimental Study on the Arduino Platform", AMBIENT 2012, The Second International Conference on Ambient Computing, Applications, Services and Technologies Barcelona, September 2012.

# Hardware Specifications

- ▶ Seeeduino development board: Atmel AVR ATmega328P
- ▶ nRF24L01 wireless interface: Nordic Semiconductor
- ▶ Sharp GP2Y0A21YK infra-red distance sensor



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# Arduino meets WSN: Sensing

- Our nodes are based on the Arduino compatible Seeeduino board.



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# Arduino meets WSN: Sensing

- ▶ Our nodes are based on the Arduino compatible Seeeduino board.
- ▶ Sensing:
  - ▶ A sensor node detects cars in parking spots using an IR distance sensor.



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- ▶ Our nodes are based on the Arduino compatible Seeeduino board.
- ▶ Sensing:
  - ▶ A sensor node detects cars in parking spots using an IR distance sensor.
  - ▶ The values coming from the distance sensors is interpreted using our own sensor library.



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# Arduino meets WSN: Sensing

- ▶ Our nodes are based on the Arduino compatible Seeeduino board.
- ▶ Sensing:
  - ▶ A sensor node detects cars in parking spots using an IR distance sensor.
  - ▶ The values coming from the distance sensors is interpreted using our own sensor library.
  - ▶ Multiple measurements are combined to confirm the presence of a car.



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# Arduino meets WSN: Communication

- ▶ The radio module: nRF24L01 (Nordic Semiconductor)
  - ▶ Ultra low power 2.4GHz RF Transceiver
  - ▶ Approximately half the power of a typical XBee RF Transceiver



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- ▶ The radio module: nRF24L01 (Nordic Semiconductor)
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  - ▶ Approximately half the power of a typical XBee RF Transceiver
  - ▶ Only Physical layer on-chip
  - ▶ Partial Link-layer through an existing Arduino library (RF24 by Maniacbug)



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  - ▶ Only Physical layer on-chip
  - ▶ Partial Link-layer through an existing Arduino library (RF24 by Maniacbug)
  - ▶ We implemented collision avoidance



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- ▶ The radio module: nRF24L01 (Nordic Semiconductor)
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  - ▶ Only Physical layer on-chip
  - ▶ Partial Link-layer through an existing Arduino library (RF24 by Maniacbug)
  - ▶ We implemented collision avoidance
  - ▶ We implemented a cluster based Layer 3 protocol, very similar to the popular LEACH protocol.



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# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.

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<sup>7</sup><http://code.google.com/p/arduino-cluster-network/>

# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.
- ▶ Used Arduino libraries
  - ▶ Sharp GP2Y0A21YK infra-red distance sensor
  - ▶ Maniacbug RF24 library
  - ▶ Low-Power library

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# Arduino Libraries

- ▶ Arduino software libraries make it straightforward for anyone to start embedded development.
- ▶ Used Arduino libraries
  - ▶ Sharp GP2Y0A21YK infra-red distance sensor
  - ▶ Maniacbug RF24 library
  - ▶ Low-Power library
- ▶ Developed Arduino libraries<sup>7</sup>
  - ▶ Cluster network library
  - ▶ Detecting car library
  - ▶ Node energy library

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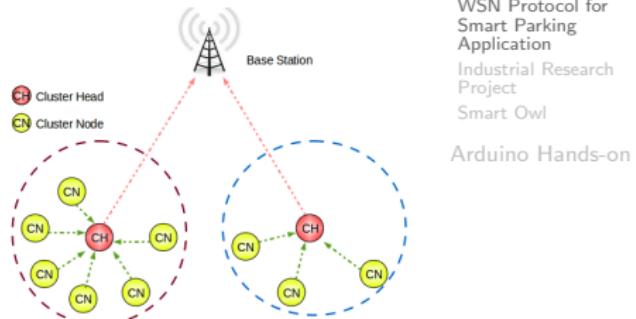
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<sup>7</sup><http://code.google.com/p/arduino-cluster-network/>

# Low Energy Adaptive Cluster Hierarchy (LEACH)

## 1. Divide the network in clusters



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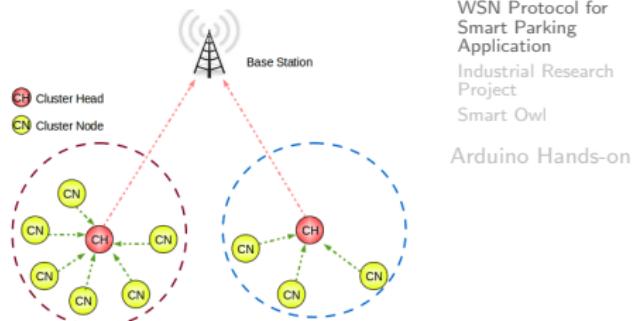
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# Low Energy Adaptive Cluster Hierarchy (LEACH)

1. Divide the network in clusters
2. Election a temporary Cluster Head (CH)



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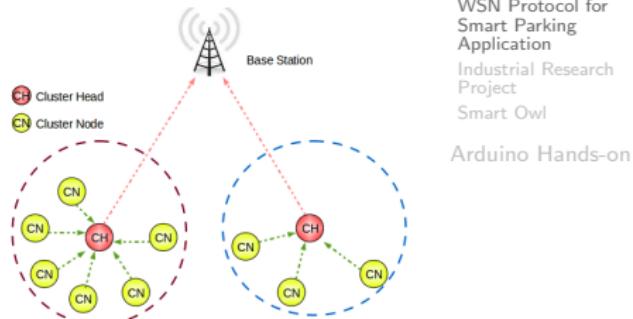
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# Low Energy Adaptive Cluster Hierarchy (LEACH)

1. Divide the network in clusters
2. Election a temporary Cluster Head (CH)
3. The CH aggregates all sensor data and forwards it to the sink



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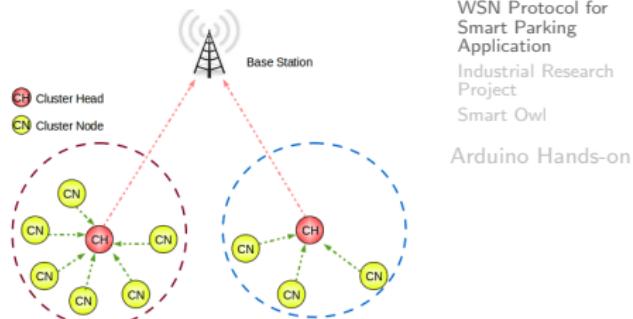
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# Low Energy Adaptive Cluster Hierarchy (LEACH)

1. Divide the network in clusters
  2. Election a temporary Cluster Head (CH)
  3. The CH aggregates all sensor data and forwards it to the sink
- During operation we have two phases:



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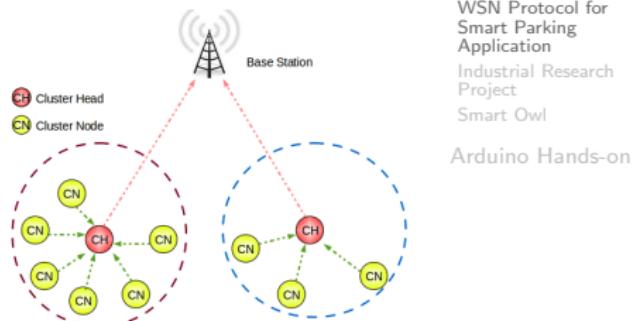
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# Low Energy Adaptive Cluster Hierarchy (LEACH)

1. Divide the network in clusters
  2. Election a temporary Cluster Head (CH)
  3. The CH aggregates all sensor data and forwards it to the sink
- During operation we have two phases:
- CH selection



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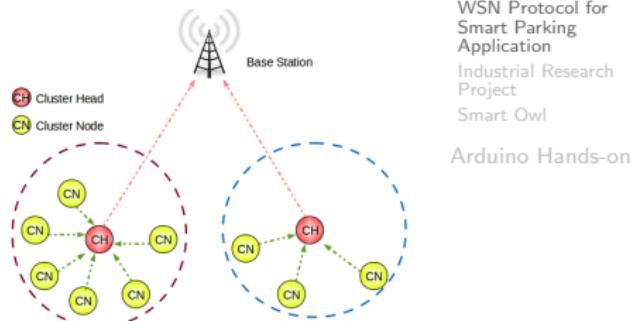
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# Low Energy Adaptive Cluster Hierarchy (LEACH)

1. Divide the network in clusters
  2. Election a temporary Cluster Head (CH)
  3. The CH aggregates all sensor data and forwards it to the sink
- During operation we have two phases:
- CH selection
  - Normal operation



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# Cluster Head Selection

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1. CH broadcasts an Energy Request message.



# Cluster Head Selection

1. CH broadcasts an Energy Request message.
2. SNs measure their energy level and send it to the CH.



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# Cluster Head Selection

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1. CH broadcasts an Energy Request message.
2. SNs measure their energy level and send it to the CH.
3. CH collects replies and compares energy levels.



# Cluster Head Selection

1. CH broadcasts an Energy Request message.
2. SNs measure their energy level and send it to the CH.
3. CH collects replies and compares energy levels.
4. Node with the most energy is selected as the new CH.



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# Cluster Head Selection

1. CH broadcasts an Energy Request message.
2. SNs measure their energy level and send it to the CH.
3. CH collects replies and compares energy levels.
4. Node with the most energy is selected as the new CH.
5. CH broadcasts the new CH ID to all SNs.



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# Cluster Head Selection

1. CH broadcasts an Energy Request message.
2. SNs measure their energy level and send it to the CH.
3. CH collects replies and compares energy levels.
4. Node with the most energy is selected as the new CH.
5. CH broadcasts the new CH ID to all SNs.
6. SNs update the CH ID at the same time.



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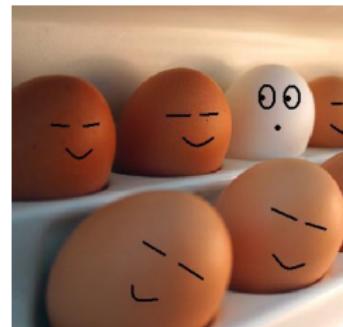
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# Sensing and Communication

## ► Sensor node:

1. Check for parking lot status change
2. Send changes to the CH
3. Go to sleep



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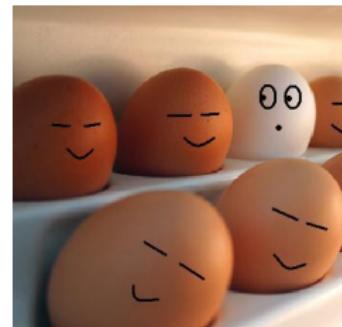
# Sensing and Communication

## ► Sensor node:

1. Check for parking lot status change
2. Send changes to the CH
3. Go to sleep

## ► Cluster head:

1. Aggregate all sensor data.
2. Forward data to the sink.
3. Go to sleep



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# Experimental Study

Evaluation and solutions to practical problems.

- ▶ Energy consumption
  - ▶ Minimise energy consumption by maximising sleep time
  - ▶ Power down external sensors

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# Experimental Study

Evaluation and solutions to practical problems.

- ▶ Energy consumption
  - ▶ Minimise energy consumption by maximising sleep time
  - ▶ Power down external sensors
- ▶ Packet Loss Ratio
  - ▶ Evaluation of packet loss ratio to ensure proper system operation

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# Experimental Study

Evaluation and solutions to practical problems.

- ▶ Energy consumption
  - ▶ Minimise energy consumption by maximising sleep time
  - ▶ Power down external sensors
- ▶ Packet Loss Ratio
  - ▶ Evaluation of packet loss ratio to ensure proper system operation
- ▶ Synchronisation
  - ▶ ATmega328P internal oscillator: significant error margin between individual sensors
  - ▶ Software based solution: recalibration in reference to CH

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# Future Work *(as presented in September 2012)*

- ▶ Further development of the proof-of-concept application
  - ▶ Server-side data management
  - ▶ Mobile phone application to search for vacant parking spots
  - ▶ Embedded display module for in-car placement

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- ▶ Further development of the proof-of-concept application
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- ▶ Protocol enhancement
  - ▶ Better scalability and security
  - ▶ Location aware cluster head selection

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  - ▶ Location aware cluster head selection
- ▶ Clean up the code and allow other people to use it
  - ▶ Better documentation
  - ▶ Easy and working examples

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<sup>8</sup>International Journal On Advances in Intelligent Systems:  
<http://www.iariajournals.org/>

# Future Work *(as presented in September 2012)*

- ▶ Further development of the proof-of-concept application
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  - ▶ Mobile phone application to search for vacant parking spots
  - ▶ Embedded display module for in-car placement
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  - ▶ Better scalability and security
  - ▶ Location aware cluster head selection
- ▶ Clean up the code and allow other people to use it
  - ▶ Better documentation
  - ▶ Easy and working examples
- ▶ We have been invited to publish an extended version of this article in a journal<sup>8</sup>

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<sup>8</sup>International Journal On Advances in Intelligent Systems:  
<http://www.iariajournals.org/>

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# Conclusions for “Smart Parking Project”

- We implemented an event-driven, hierarchical WSN clustering protocol with an energy-aware CH selection algorithm similar to the LEACH protocol.

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# Conclusions for “Smart Parking Project”

- ▶ We implemented an event-driven, hierarchical WSN clustering protocol with an energy-aware CH selection algorithm similar to the LEACH protocol.
- ▶ We used Seeeduino development boards, nRF24L01 low-power RF modules and Sharp IR distance sensors.

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- ▶ We implemented an event-driven, hierarchical WSN clustering protocol with an energy-aware CH selection algorithm similar to the LEACH protocol.
- ▶ We used Seeeduino development boards, nRF24L01 low-power RF modules and Sharp IR distance sensors.
- ▶ Our synchronisation mechanism solves the problems caused by the inaccuracy of the Arduino internal Timer.

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# Conclusions for “Smart Parking Project”

- ▶ We implemented an event-driven, hierarchical WSN clustering protocol with an energy-aware CH selection algorithm similar to the LEACH protocol.
- ▶ We used Seeeduino development boards, nRF24L01 low-power RF modules and Sharp IR distance sensors.
- ▶ Our synchronisation mechanism solves the problems caused by the inaccuracy of the Arduino internal Timer.
- ▶ Preliminary measurement results show that the hardware choices were not optimal for this WSN Application.

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# Conclusions for “Smart Parking Project”

- ▶ We implemented an event-driven, hierarchical WSN clustering protocol with an energy-aware CH selection algorithm similar to the LEACH protocol.
- ▶ We used Seeeduino development boards, nRF24L01 low-power RF modules and Sharp IR distance sensors.
- ▶ Our synchronisation mechanism solves the problems caused by the inaccuracy of the Arduino internal Timer.
- ▶ Preliminary measurement results show that the hardware choices were not optimal for this WSN Application.
- ▶ Although Arduino is easy to use as an experimental open-source platform, it is currently not the most appropriate platform to develop low-power WSN applications.

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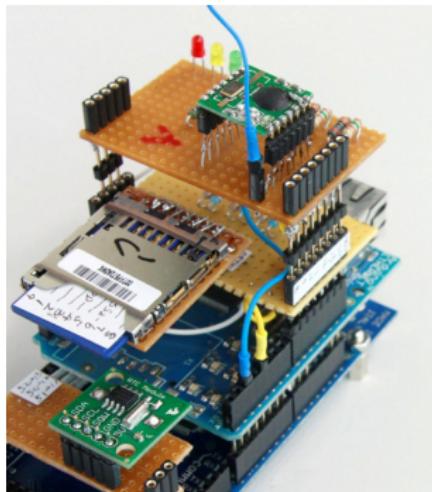
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# Part 1: Arduino Sensor Module

- ▶ Arduino module equipped with:



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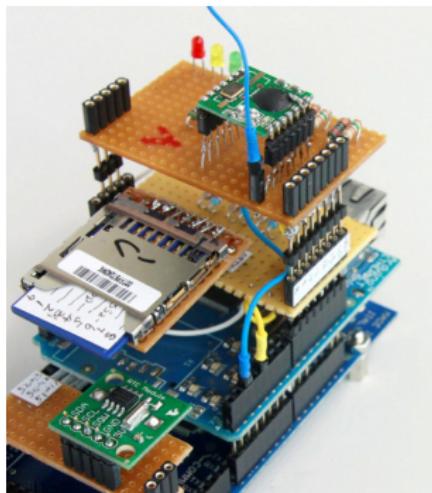
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# Part 1: Arduino Sensor Module

- ▶ Arduino module equipped with:
- ▶ Multiple sensors:
  - ▶ Distance, temperature, humidity,....



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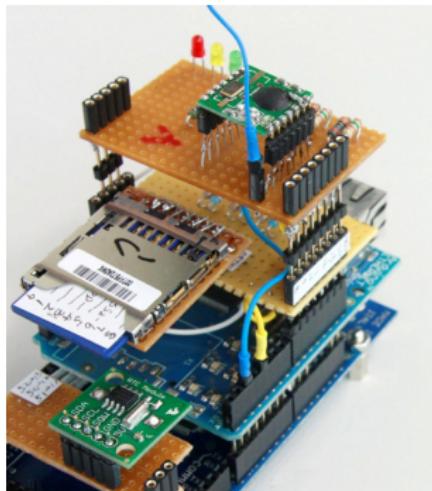
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# Part 1: Arduino Sensor Module

- ▶ Arduino module equipped with:
- ▶ Multiple sensors:
  - ▶ Distance, temperature, humidity,....
- ▶ Motor control
  - ▶ 12V DC motor with a “reasonable power”



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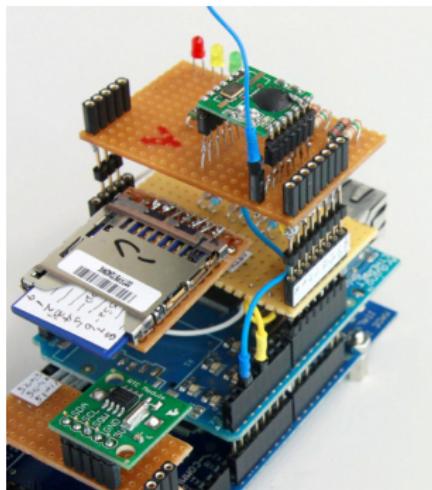
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# Part 1: Arduino Sensor Module

- ▶ Arduino module equipped with:
- ▶ Multiple sensors:
  - ▶ Distance, temperature, humidity,...
- ▶ Motor control
  - ▶ 12V DC motor with a “reasonable power”
- ▶ Wireless communication
  - ▶ WiFi, ZigBee, nRF24,...



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# Part 2: Cloud Connection

- ▶ Data sink
  - ▶ Collecting sensor data
  - ▶ MySQL database



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# Part 2: Cloud Connection

- ▶ Data sink
  - ▶ Collecting sensor data
  - ▶ MySQL database
- ▶ Send commands to module
  - ▶ Motor control, change sampling rate,...
  - ▶ Web interface: php, JavaScript



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# Part 2: Cloud Connection

- ▶ Data sink
  - ▶ Collecting sensor data
  - ▶ MySQL database
- ▶ Send commands to module
  - ▶ Motor control, change sampling rate,...
  - ▶ Web interface: php, JavaScript
- ▶ GUI for data analysis



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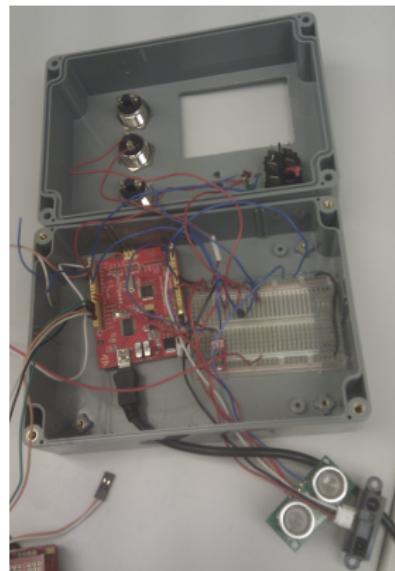
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# Embedded Hardware Prototype

- ▶ Hardware:
  - ▶ Demo module on a breadboard
- ▶ Sensors:
  - ▶ Temperature & Humidity
  - ▶ Distance (IR & ultrasonic)
  - ▶ Pushbuttons
- ▶ RF: WiFly modules (IEEE 802.11)



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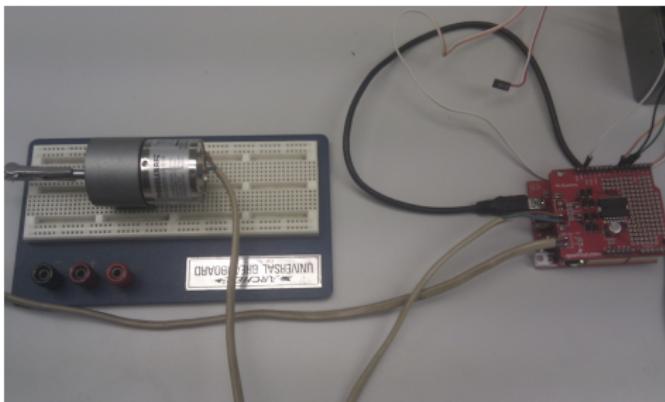
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# Embedded Hardware Prototype

- ▶ Motor control:
  - ▶ Ardumoto shield to control a DC motor
  - ▶ Connected with three wires for an early demo
  - ▶ To show the concept, the next version would be on one PCB.



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# Embedded Arduino Software

- ▶ New Software libraries: level 1: GPL (currently online at Google Code)
  - ▶ Ardumoto, DistanceSensor, TemperatureTMP, HumidityHIH4030
  - ▶ SerialPacket: minimal packet based serial communication
  - ▶ SignalFilter: filtering sensor data
  - ▶ SerialConfigMenu: change module setting over the serial port
- ▶ New Software libraries: level 2: not available online
  - ▶ AmbientSensing: combination of temperature and humidity
  - ▶ DistanceSensing: sensor fusion distance + filtering
- ▶ New Software libraries: level 3: Project specific code, not available online
  - ▶ Implementation of complete system, demo applications, unit tests

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# Top-level Software: state machine

```
void Module::stateMachine()
{
    switch(getState() ) {
        case SELFCHECK\_STATE:
            // Verify all sensors ok
            // Do motor test?
            // Do other self test?
            // Move to STARTUP state if everything ok
            setOuterState(STARTUP\_STATE);
            break;

        case STARTUP\_STATE:
            // Send data to server to test uplink?
            // Move to running state if everything ok
            setOuterState(RUNNING\_STATE);
            break;

        case RUNNING\_STATE:
            sensorHandling();
            packetHandling();
            break;
    }
}
```

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# Top-level Software: main actions

```
void Module::sensorHandling()
{
```

```
    readSensors();
    sensorActions();
    sensorReporting();
```

```
}
```

```
void Module::packetHandling()
```

```
{
```

```
    serialActions();
    serialReporting();
```

```
}
```

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# Summary of Server Side Software

- ▶ Database design
- ▶ Web interface: php, JavaScript, ...
- ▶ SerialForwarder: parsing “SerialPacket-data” and connection to MySQL (first version in C#, second in C++)
- ▶ Serial packet forwarder: connection between Arduino and database
- ▶ Test applications with node.js
- ▶ Serial packet analyser (Java)
- ▶ RRDtool plugin (data logging tool for IT systems)

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# Local data-sink: Embedded Linux

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- ▶ Server-side application is moved to an embedded Linux board: BeagleBone
- ▶ PCB design: Beagluino: “BeagleBone Cape”
  - ▶ Extension module for BeagleBone
  - ▶ Contains: Arduino, motor driver IC, sensors, multiple I/O connectors

# New System Controller (Python)

- ▶ Many new features requested in phase 2 of the project
  - ▶ More and different sensors, multiple data flows,...
- ▶ The existing software blocks have been rewritten and merged into one application written in Python.
  - ▶ `serial_read_thread`, `serial_write_thread`,  
`databasepush_sensor_thread`,  
`databasepush_cmd_thread`, `databasepoll_thread`,  
`erase_monitoring_thread`
  - ▶ Debian package, PyPI compatible package<sup>9</sup>

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<sup>9</sup>The Python Package Index: <http://pypi.python.org>

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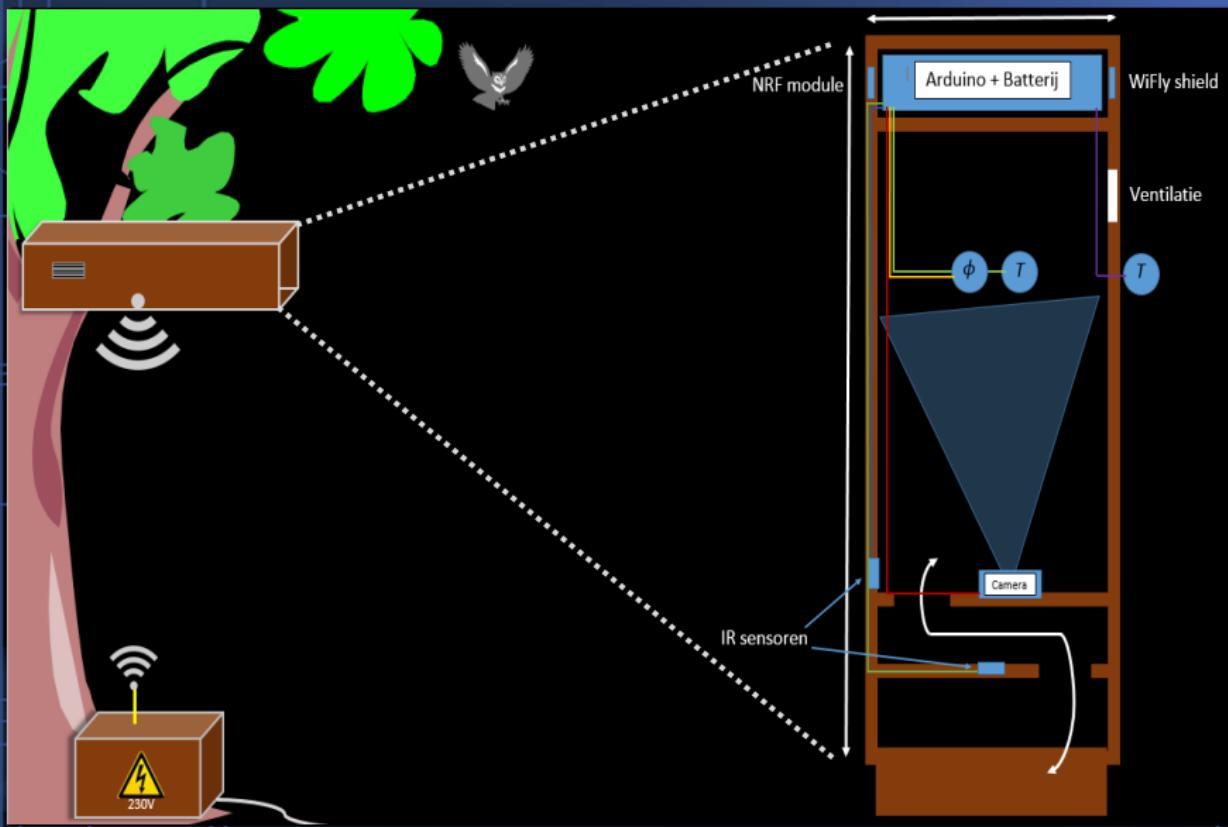


Smart Objects

# Project: Birdhouse

# Approach

- The questions
- OneTeam per module
- Integration of modules



# Nestkast

	Sensors	Microcontroller
Temperature	TMP 36GZ	Arduino Mega
Humidity	HIH-4030	
Camera	JPEG Color Camera	
Datatransfer	NRF-24 LR WiFly Shield	
IR detection	IR LED transciever	
Power	Batterij	
Data storage	Micro SD	

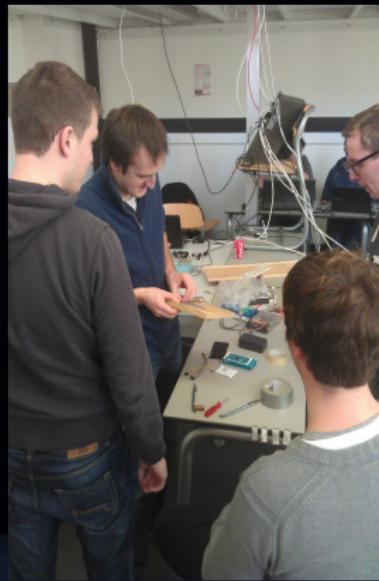


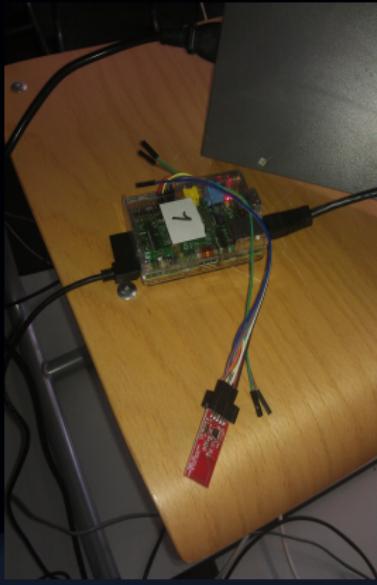
# Datacenter

	Microcontroller		
Power	230V	Arduino Uno	Raspberry Pi
Data storage	Micro SD		
Data tranceiver	NRF-24 LR		
	WiFi Shield		

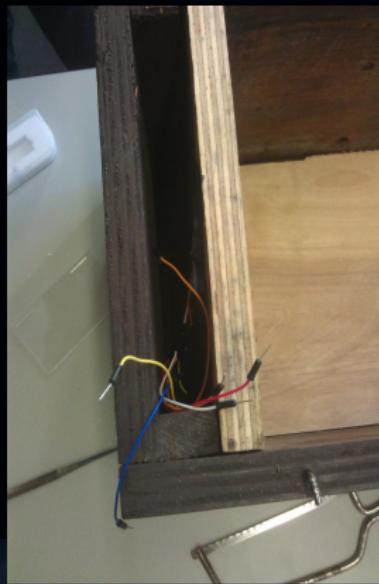
# Progress

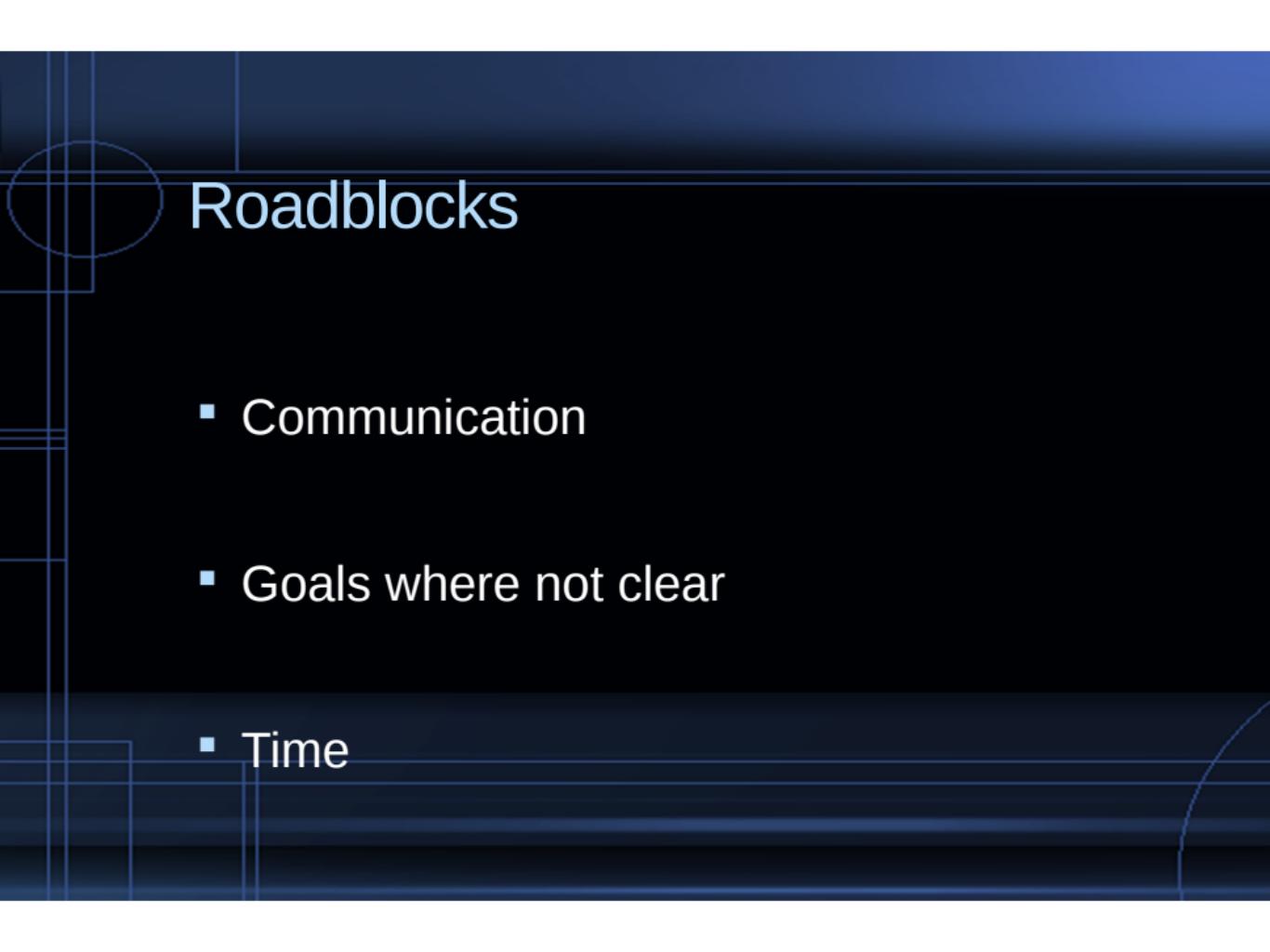
- Finished
  - humidity, entry detection, temp. op SD
  - photo's op SD
  - wiring
- In progress
  - wireless communication
  - Further integration











# Roadblocks

- Communication
- Goals where not clear
- Time

# Results

- Wooden house (not pretty)
- Loose wires
- Disorder
- No battery
- Software needs finetuning

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# Arduino Hands-on

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Arduino Hands-on

- ▶ Writing a Library for Arduino<sup>10</sup>
- ▶ Use a good code editor with syntax highlighting (e.g. bluefish<sup>11</sup>, Notepad++<sup>12</sup>).
- ▶ Follow me and test the code on your own PC & Arduino board as we go through the tutorial together.

---

<sup>10</sup><http://arduino.cc/en/Hacking/LibraryTutorial>

<sup>11</sup><http://bluefish.openoffice.nl>

<sup>12</sup><http://notepad-plus-plus.org>

# Morse code: Sending “SOS” signal

- ▶ Without software library:
  - ▶ Complicated code
  - ▶ Verbose code

```
int pin = 13;  
  
void setup()  
{  
    pinMode(pin, OUTPUT);  
}  
  
void loop()  
{  
    dot(); dot(); dot();  
    dash(); dash(); dash();  
    dot(); dot(); dot();  
    delay(3000);  
}  
  
void dot()  
{  
    digitalWrite(pin, HIGH);  
    delay(250);  
    digitalWrite(pin, LOW);  
    delay(250);  
}  
  
void dash()  
{  
    digitalWrite(pin, HIGH);  
    delay(1000);  
    digitalWrite(pin, LOW);  
    delay(250);  
}
```

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Industrial Research Project

Smart Owl

Arduino Hands-on

# Morse code: Morse.h

- ▶ Morse class
- ▶ More structure

```
#ifndef Morse_h
#define Morse_h

#include "Arduino.h"

class Morse
{
public:
    Morse(int pin);
    void dot();
    void dash();
private:
    int _pin;
};

#endif
```

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# Morse code: Morse.cpp

- ▶ Implementation
- ▶ Low level code

```
#include "Morse.h"

Morse::Morse(int pin)
{
    pinMode(pin, OUTPUT);
    _pin = pin;
}

void Morse::dot()
{
    digitalWrite(_pin, HIGH);
    delay(250);
    digitalWrite(_pin, LOW);
    delay(250);
}

void Morse::dash()
{
    digitalWrite(_pin, HIGH);
    delay(1000);
    digitalWrite(_pin, LOW);
    delay(250);
}
```

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# Morse code: Morse.ino

## ► Better code:

- More structure
- Easy to understand
- Implementation hidden

```
#include <Morse.h>

Morse morse(13);

void setup()
{
}

void loop()
{
    morse.dot(); morse.dot(); morse.dot();
    morse.dash(); morse.dash(); morse.dash();
    morse.dot(); morse.dot(); morse.dot();
    delay(3000);
}
```

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# Morse code: Morse.ino (version 2)

## ► New functions:

- Send letter “s”
- Send letter “o”

```
#include <Morse.h>

Morse morse(13);

void setup()
{
}

void loop()
{
    morse.letter_s();
    morse.letter_o();
    morse.letter_s();
    delay(3000);
}
```

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# Morse code: Morse.ino (version 3)

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- ▶ New functions:
  - ▶ Send “SOS”

```
#include <Morse.h>

Morse morse(13);

void setup()
{
}

void loop()
{
    morse.sos();
    delay(3000);
}
```

# Thank you for your attention!



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