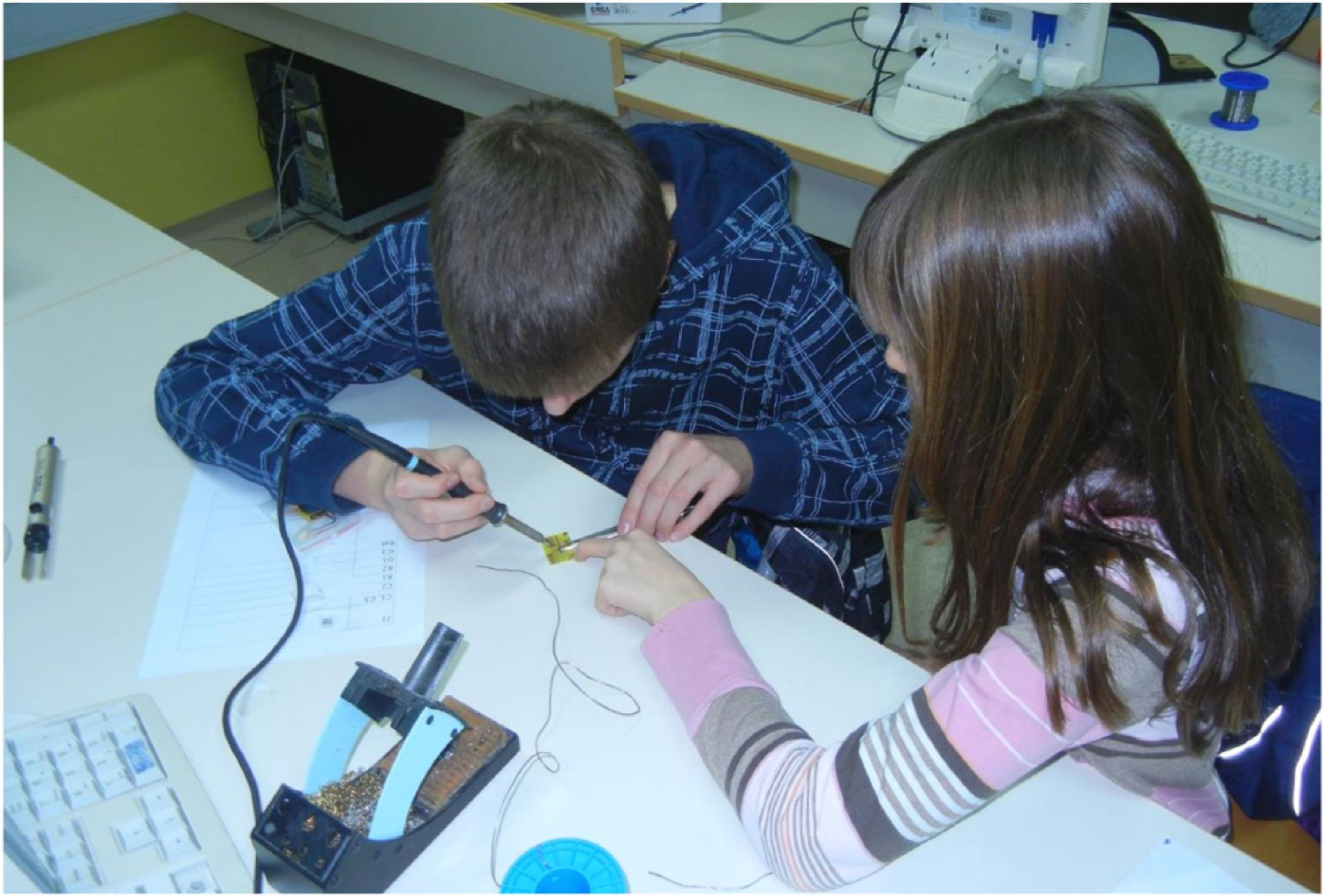
Marko Pavlin, PhD

Smart nesting box

Tool for remote wild life observation

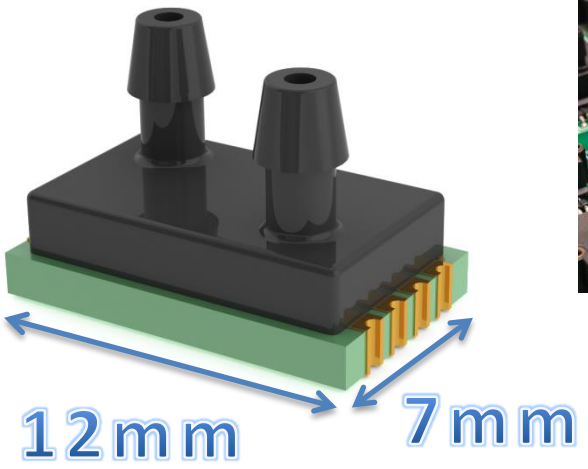


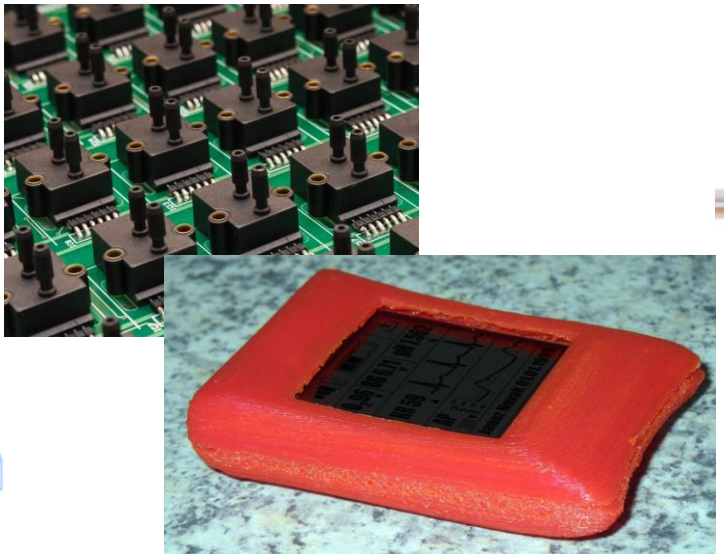
Ask questions:

The Single Most Important Habit for Innovative Thinkers

Marko Pavlin

- 25 years experience in electronics R&D
  - sensors, microcontrollers
  - automotive, industrial and medical
- Company HYB and Institute Jožef Stefan





Meet the team

- Assembled in Oct. 2016
- **Radio club Novo mesto** organised workshop for pupil from elementary school
  - 8 paricipants **aged 10 to 13**
  - Main project: **smart nesting box**

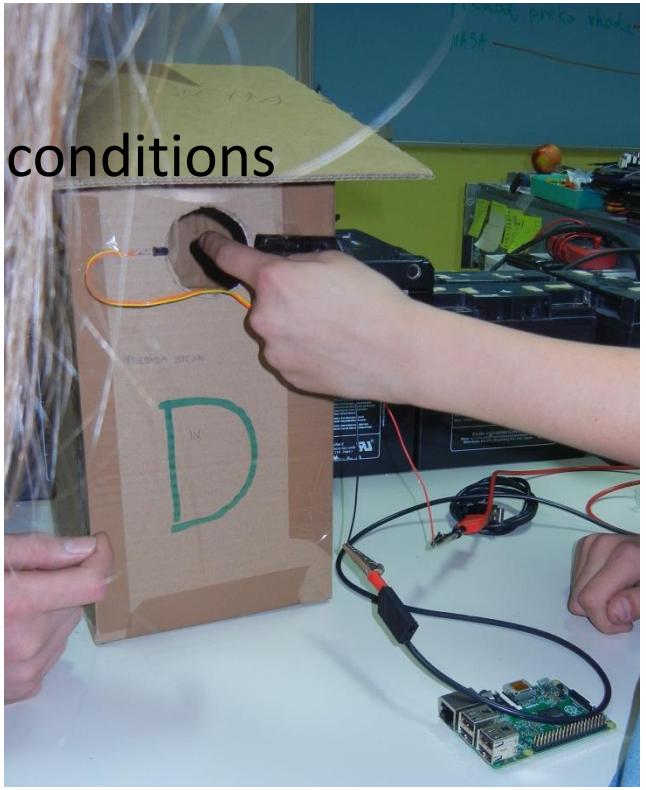
- SEŠTG Novo mesto:
  - 2 mentors
  - Place for meetings
- Elementary school Grm Novo mesto:
  - 8 participants
- Radio Club:
  - 2 mentors
  - Administration
- Sponsors

Contents

- Introduction
- Sensors
  - Pressure
  - RH
  - Temperature
- Microcontroller
  - Hardware
  - Programming
- Raspberry Pi
  - Hardware
  - Programming
- Data flow
  - Sensors
  - Video
- Long range WiFi
- Conclusion
- Q&A

Why smart nesting box?

- Camera-based bird nest surveillance
  - non-invasive method
  - substitute for standard observational methods
  - reduces disturbance
  - can gather information during worse conditions
- Additional parameters
  - Temperature
  - Humidity
  - Air pressure
  - Illumination
  - Sound



Similar projects

Principal investigator: Markéta Zárybnická
Project partners: Czech University of Life Science Prague, Czech Technical University in Prague

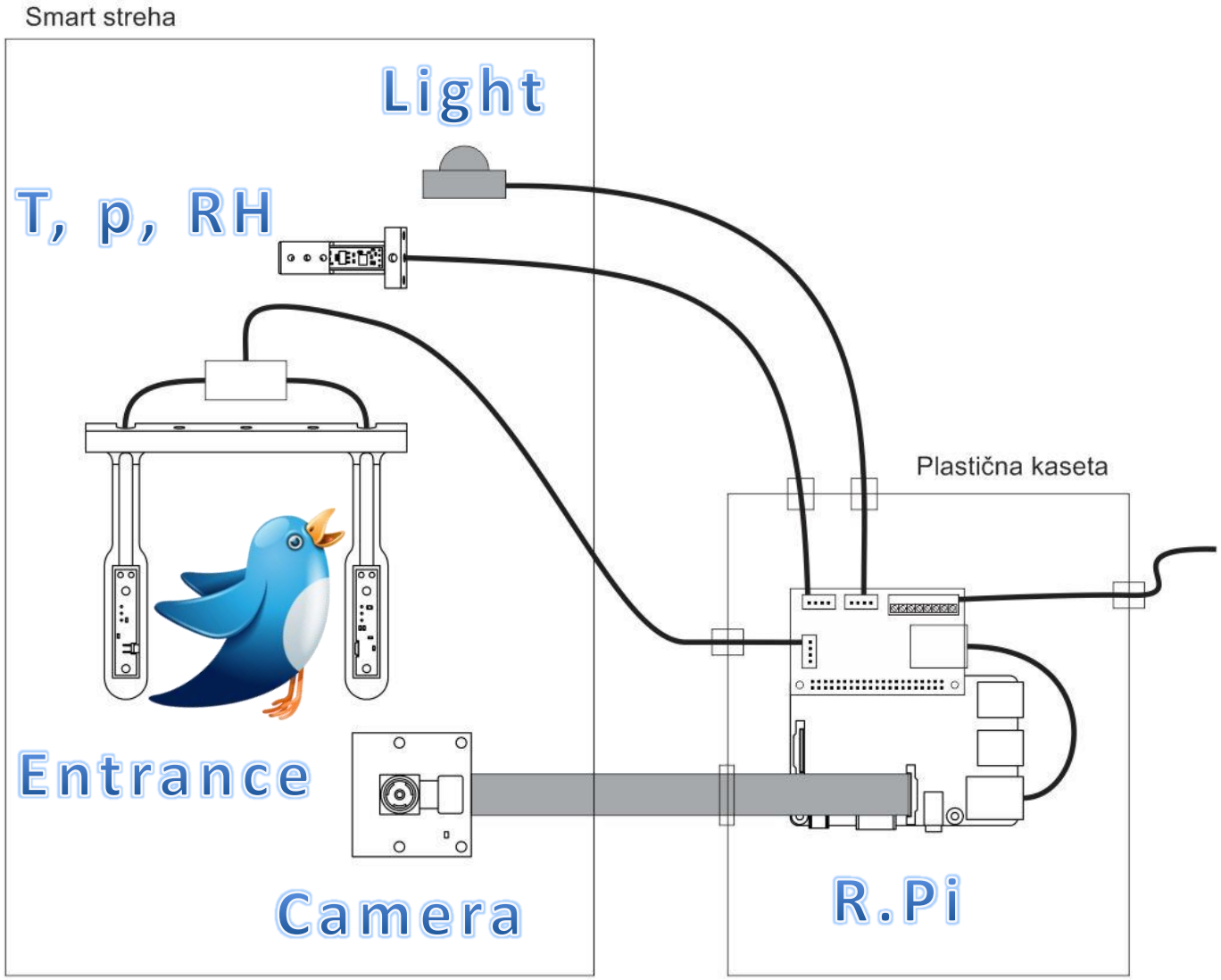
Advantage: placed in the wood, observation of rare birds

Disadvantage: have to change heavy battery every 5 days, not online

First mockup

- Cut from cardbox
- Check the components layout
- Tested some sensors
- Get "impression" about the size
- Getting seroius about project: Start early with Hands-on work

Block diagram



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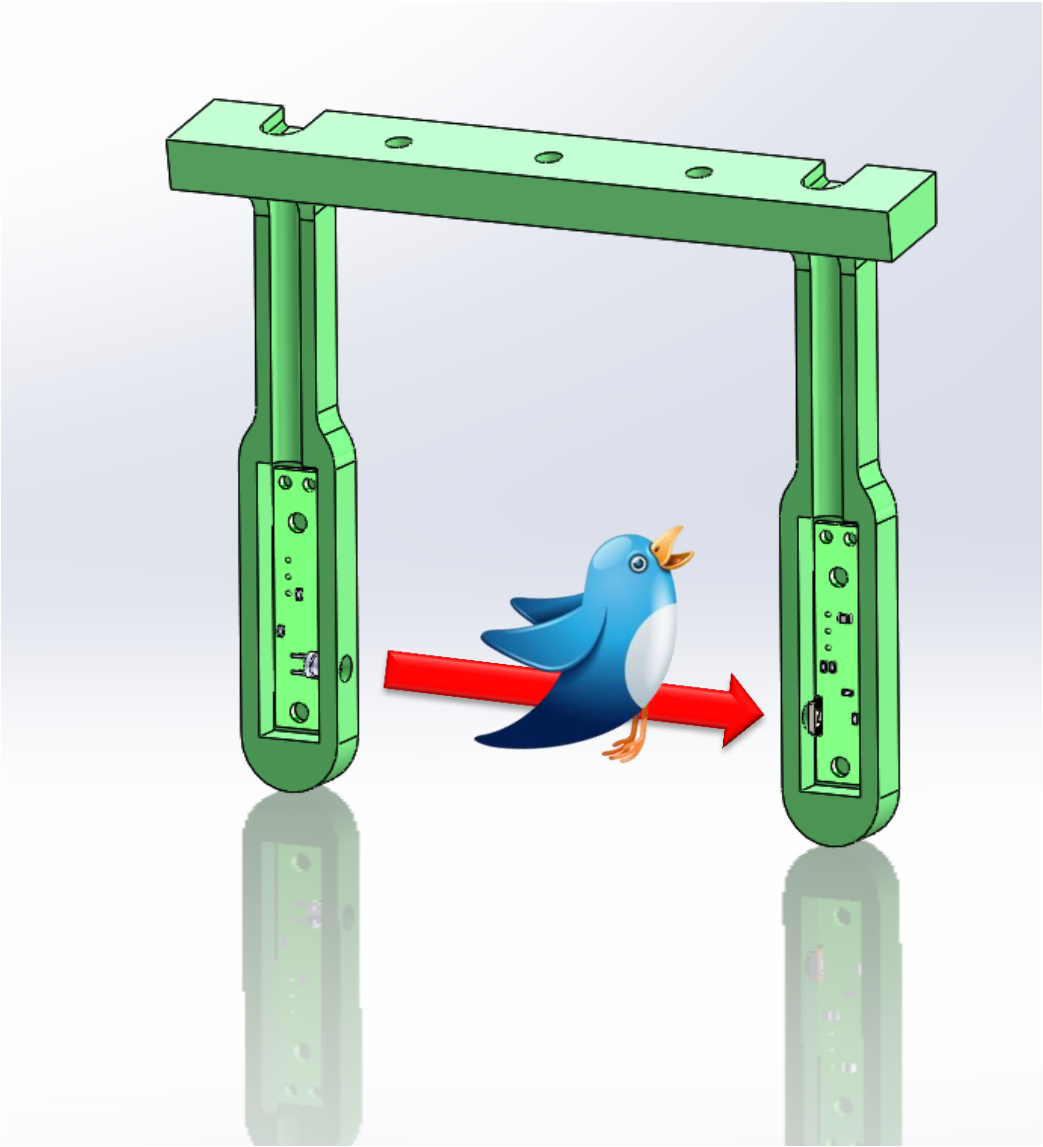
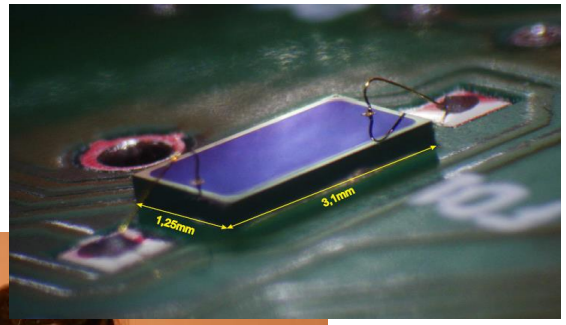
Optical barrirer sensor

- Infrared wavelength
- LED
- Photo diode
- 3,3V signals
- 5V supply



Prototype



IR LED

Photo diode
(inside cover)

Circuit

Learning electronics: photodiode

4.7.1.1.1. Generation of electron hole pairs

The generation of electron-hole pairs in a semiconductor is directly related to the absorption of light since every absorbed photon generates one electron-hole pair. The optical generation rate g_{op} is given by:

$$g_{op} = -\frac{1}{A}\frac{dP_{opt}}{dx}\frac{1}{h\nu} = \frac{\alpha P_{opt}}{Ah\nu} \tag{4.7.4}$$

where A is the illuminated area of the photodiode, P_{opt} is the incident optical power, α is the absorption coefficient and $h\nu$ is the photon energy. Note that the optical power is position dependent and obtained by solving:

$$\frac{dP_{opt}}{dx} = -\alpha P_{opt} \tag{4.7.5}$$

The resulting generation rate must be added to the continuity equation and solved throughout the photodiode, which results in the photocurrent.

4.7.1.1.2. Photocurrent due to absorption in the depletion region

Assuming that all the generated electron-hole pairs contribute to the photocurrent, the photocurrent is simply the integral of the generation rate over the depletion region:

$$I_{ph} = -qA\int_{-x_p}^{x_n+d} g_{op}dx \tag{4.7.6}$$

where d is the thickness of the undoped region. The minus sign is due to the sign convention indicated on Figure 4.7.1. For a P-i-N diode with heavily doped n-type and p-type regions and a transparent top contact layer, this integral reduces to:

$$I_{ph} = -\frac{q(1-R)P_{in}}{h\nu}(1-e^{-\alpha d}) \tag{4.7.7}$$

where P_{in} is the incident optical power and R is the reflection at the surface.

4.7.1.1.3. Photocurrent due to absorption in the quasi-neutral region

To find the photocurrent due to absorption in the quasi-neutral region, we first have to solve the diffusion equation in the presence of light. For holes in the n-type contact layer this means solving the continuity equation:

$$\frac{\partial p_n}{dt} = -\frac{1}{q}\frac{\partial J_p}{dx} + \frac{p_n - p_{n0}}{\tau_p} + g_{op}(x) \tag{4.7.8}$$

Where the electron-hole pair generation g_{op} depends on position. For an the n-type contact layer with the same energy bandgap as the absorption layer, the optical generation rate equals:

$$g_{op}(x) = \frac{P_{in}(1-R)\alpha e^{-\alpha x}}{Ah\nu} \tag{4.7.9}$$

and the photocurrent due to holes originating in the n-type contact layer equals:

$$I_{ph} = -\frac{q(1-R)P_{in}e^{-\alpha d}}{h\nu}\frac{\alpha L_p}{1+\alpha L_p}(1-e^{-\alpha d}) - \frac{qD_p p_{n0}}{L_p} \tag{4.7.10}$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} - \frac{np-n_i^2}{n+p+2n_i}\frac{1}{\tau_0} + g_{op}(x,t) \tag{4.7.39}$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} - \frac{np-n_i^2}{n+p+2n_i}\frac{1}{\tau_0} + g_{op}(x,t) \tag{4.7.40}$$

with

$$J_n = q\mu_n n\mathcal{E} + qD_p\frac{\partial n}{\partial x} \tag{4.7.41}$$

$$J_p = q\mu_p p\mathcal{E} - qD_n\frac{\partial p}{\partial x} \tag{4.7.42}$$

and the electric field is obtained from Gauss's law. For a P-i-n diode with generation only at $t = 0$ and neglecting recombination and diffusion these equations reduce to:

$$\frac{\partial n}{\partial t} = \frac{\partial n}{\partial x}\mu_n\mathcal{E} \text{ and } \frac{\partial p}{\partial t} = -\frac{\partial p}{\partial x}\mu_p\mathcal{E} \tag{4.7.43}$$

Where the electric field, $\mathcal{E}$, is assumed to be a constant equal to:

$$\mathcal{E} = \frac{\mathcal{V} - V_a}{d} \tag{4.7.44}$$

replacing $n(x,t)$ by $n^*(x - v_{nt})$ and $p(x,t)$ by $p^*(x - v_{pt})$ yields $v_n = -\mu_n\mathcal{E}$ and $v_p = \mu_p\mathcal{E}$.

The carrier distributions therefore equal those at $t = 0$ but displaced by a distance $\mu_n\mathcal{E}t$ for holes and $-\mu_p\mathcal{E}t$ for electrons. The total current due to the moving charge is a displacement current which is given by:

$$I_{ph}(t) = \frac{dQ}{dt} = \iiint\frac{\rho}{d}\frac{dx}{dt}dV = \frac{A}{d}\int_0^d \rho v dx \tag{4.7.45}$$

$$J_{ph}(t) = q\frac{A}{d}\mathcal{E}\int_0^d(\mu_n n + \mu_p p)dx \tag{4.7.46}$$

$$J_{ph}(t) = q\frac{A(\mathcal{V} - V_a)}{d^2}[\mu_n n + \mu_p p] \tag{4.7.47}$$

for $t < |d/v_n|$ and $t < |d/v_p|$. For a uniform carrier generation this reduces to:

$$I_{ph}(t) = \frac{qA(\mathcal{V} - V_a)}{d^2}[\mu_n n_0^*(d - |v_n t|) + \mu_p p_0^*(d - |v_p t|)] \tag{4.7.48}$$

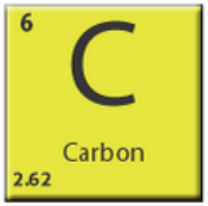
$$I_{ph}(t) = \frac{qA(\mathcal{V} - V_a)}{d}[\mu_n n_0^*(1 - \frac{|v_n t|}{d}) + \mu_p p_0^*(d - \frac{|v_p t|}{d})] \tag{4.7.49}$$

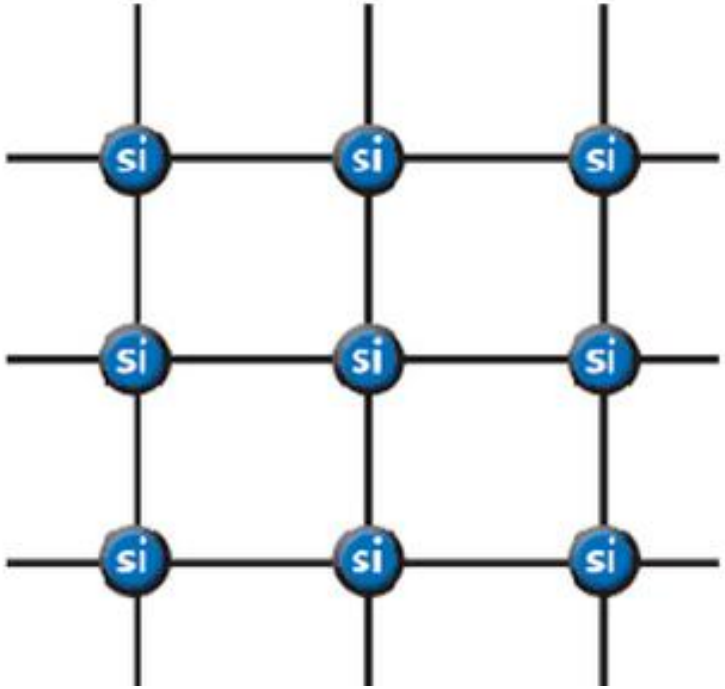
In the special case where $v_n = v_p$ or $\mu_n = \mu_p$, the full width half maximum (FWHM) of the impulse response is:

$$\text{FWHM} = \frac{d}{|v_n|^2} = \frac{d^2}{2\mu_n(\mathcal{V} - V_a)} = \frac{t_r}{2} \text{ with } t_r = \frac{d^2}{\mu_n(\mathcal{V} - V_a)} \tag{4.7.50}$$

Semiconductors

- 4 electrons
- Perfect covalent bond
  - all electrons "taken"
  - Insulator



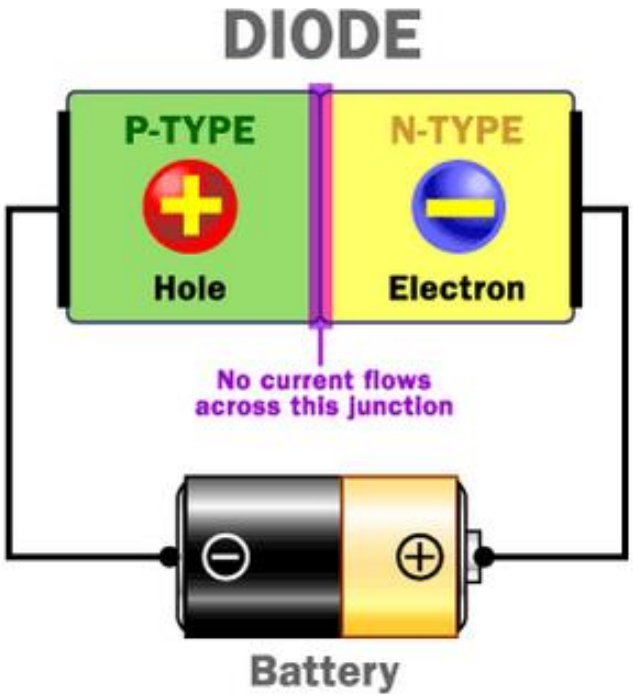


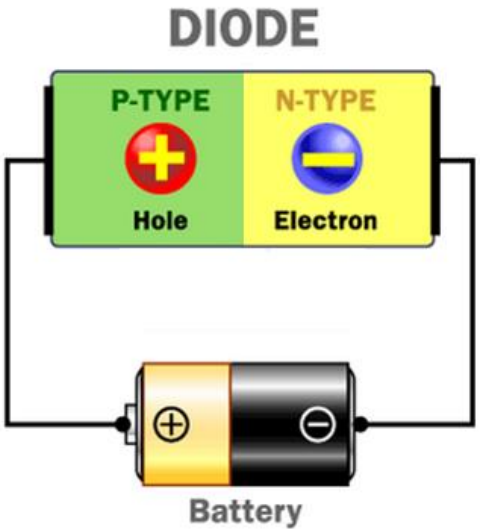
Doping silicon

- **N-type**
  - phosphorus
  - arsenic
- **P-type**
  - boron
  - gallium

Diode

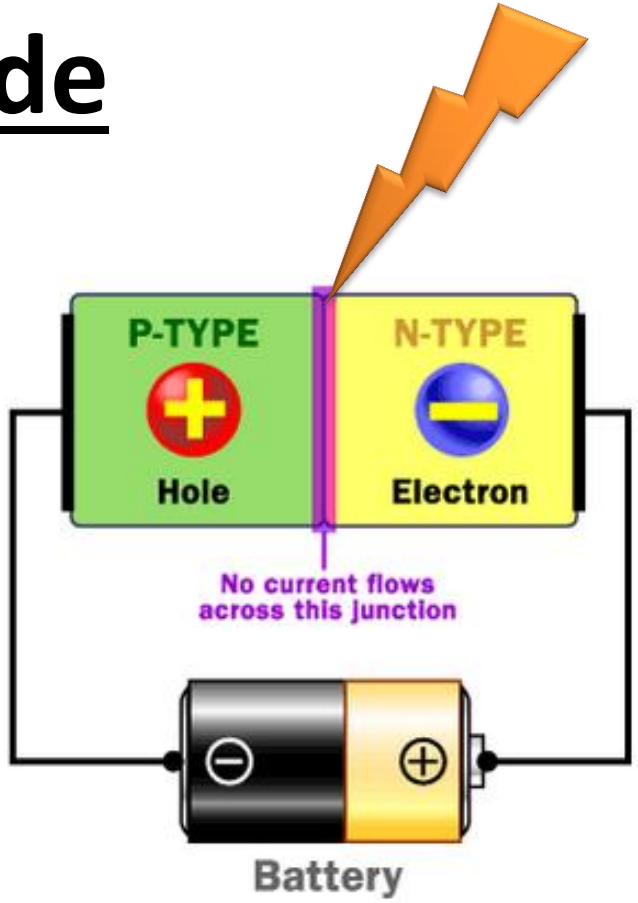
- Put N-type and P-type silicon together
- diode is the simplest possible semiconductor device

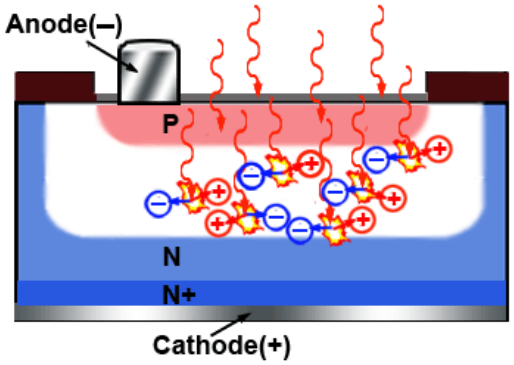


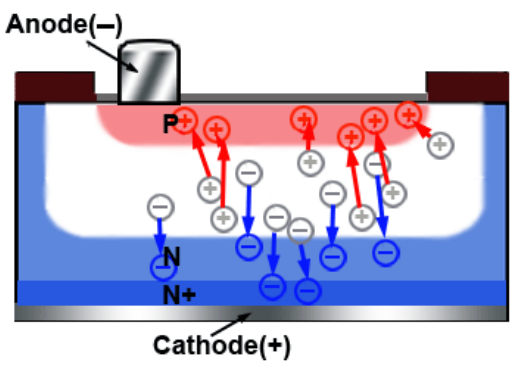


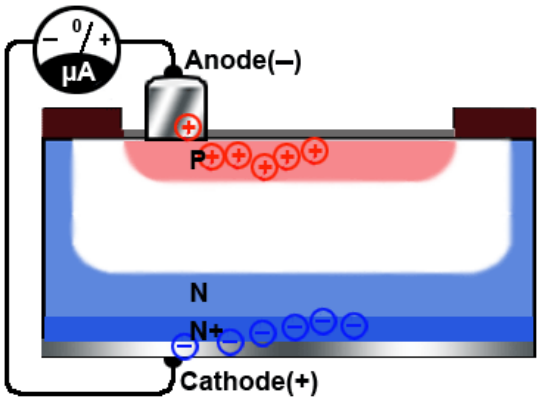
Photo**diode**

- Reverse biased
- No current flows
- When illuminated (Light???)
  - Electrons are energised
  - e- move to +
  - p+ move to -
- This makes current flow



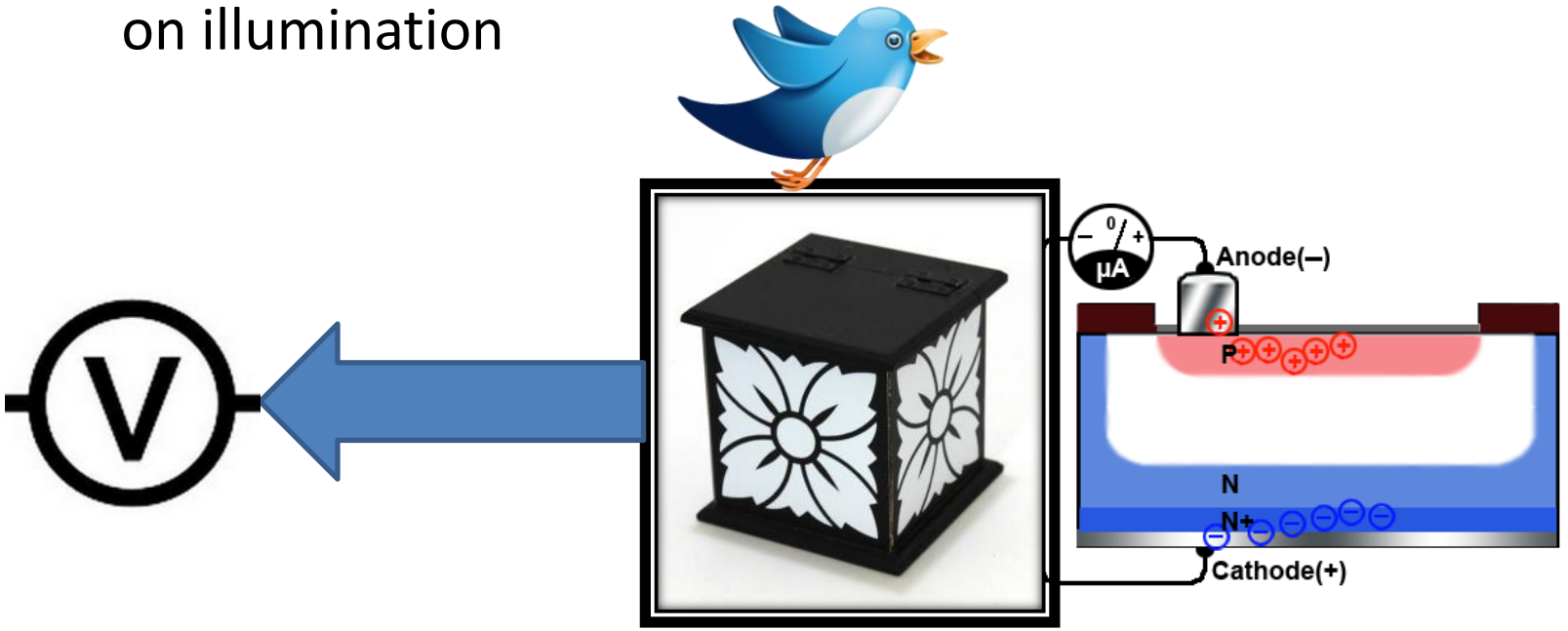




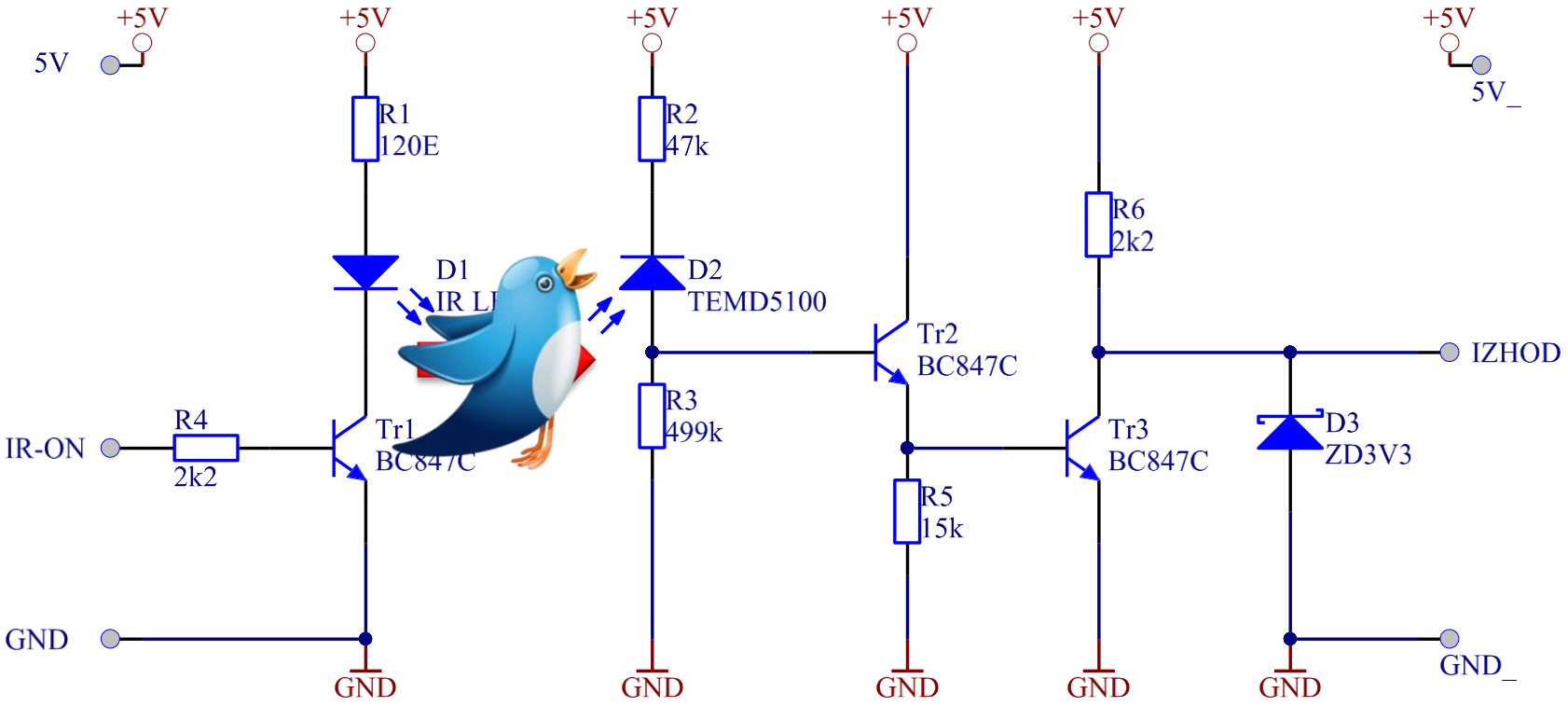


Make circuit out of photodiode

- Use light source
- Add photodiode
- Construct "mistery box":
  - Ouput voltage depends on illumination

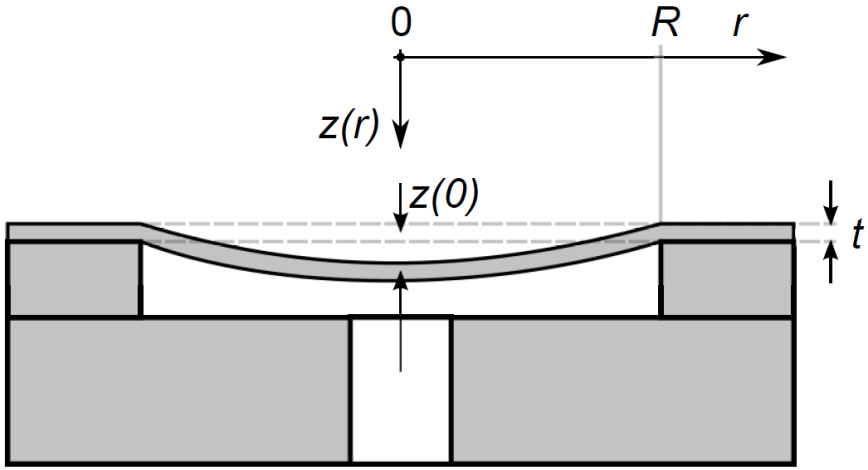


Optical barrirer sensor



Pressure sensor

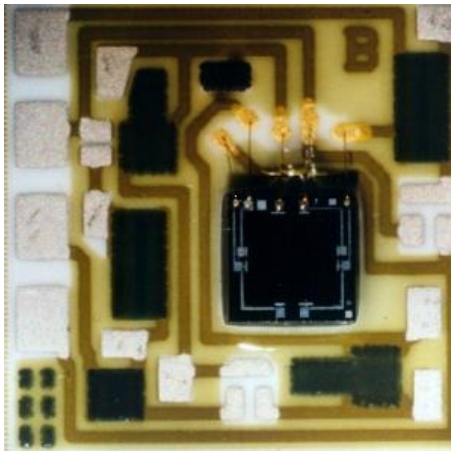
- What is pressure?
  - Force per area
  - Units?
- What happens to material when force is applied?
  - It deforms
- What if the material is membrane?
  - It bends

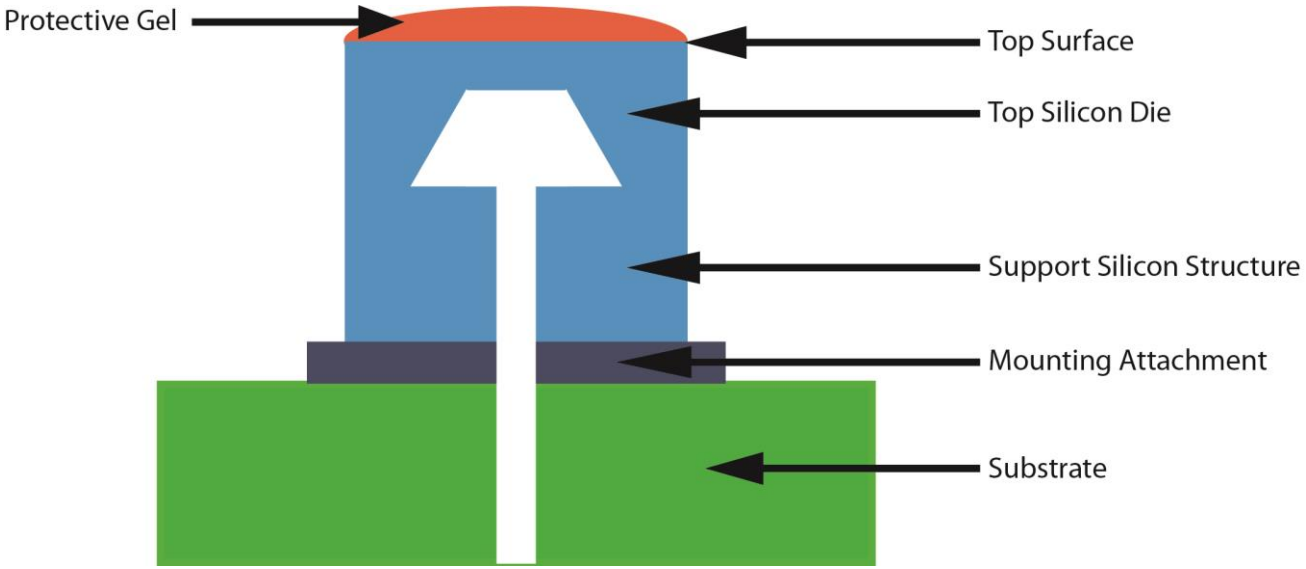


$$y(r) = \frac{3p(1-\nu^2)(R^2-r^2)^2}{16Et^3}$$

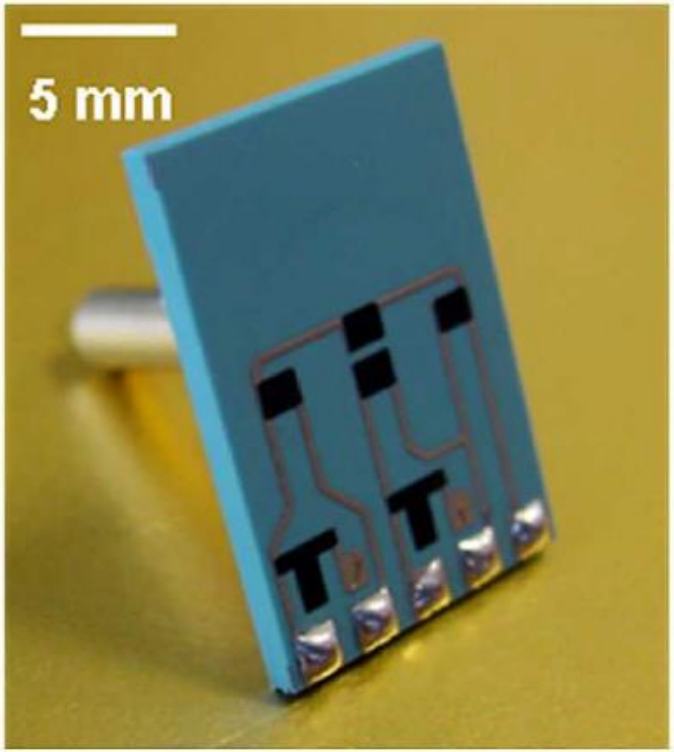
Pressure sensor

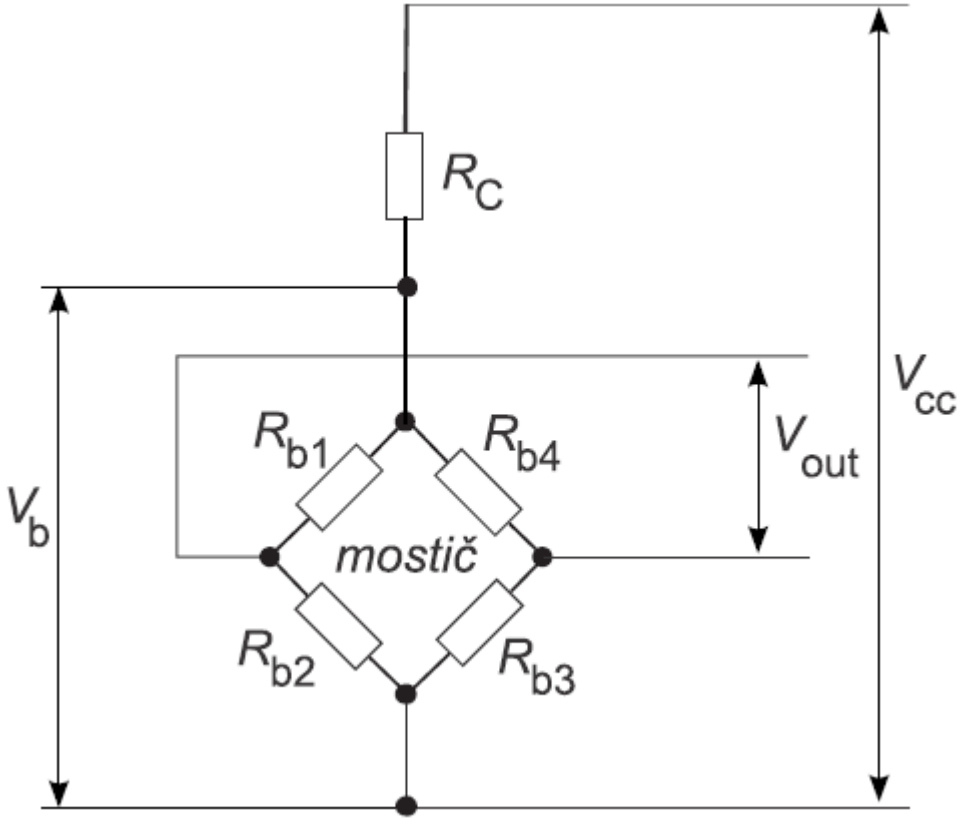
- What is inside?
  - Resistors on thin membrane



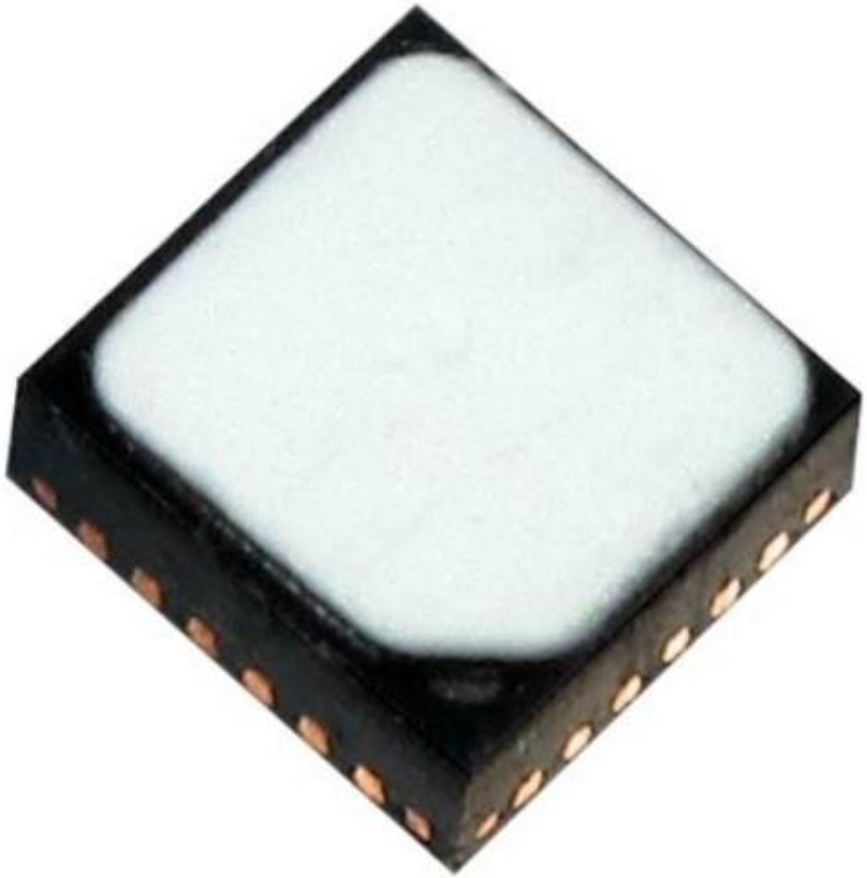


Pressure sensor

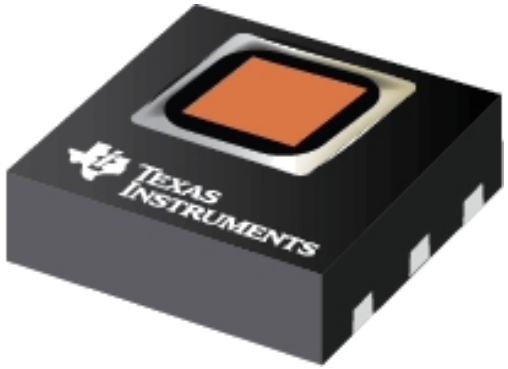




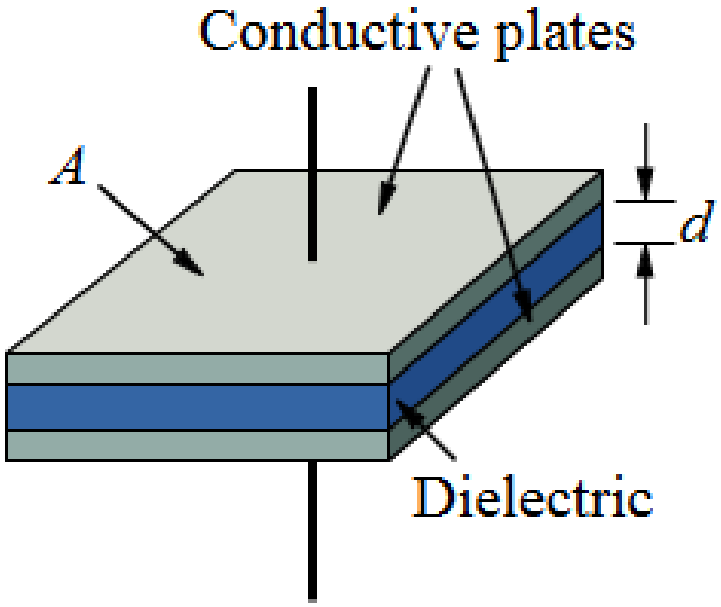
Humidity sensors



Humidity sensor



- Most common RH sensors
  - Polyimide film
  - Deposited over a metal finger **capacitor**
  - **Change in capacitance**
- Readout electronics
  - single chip integration
  - T and RH readout
  - digital interface
  - low power consumption



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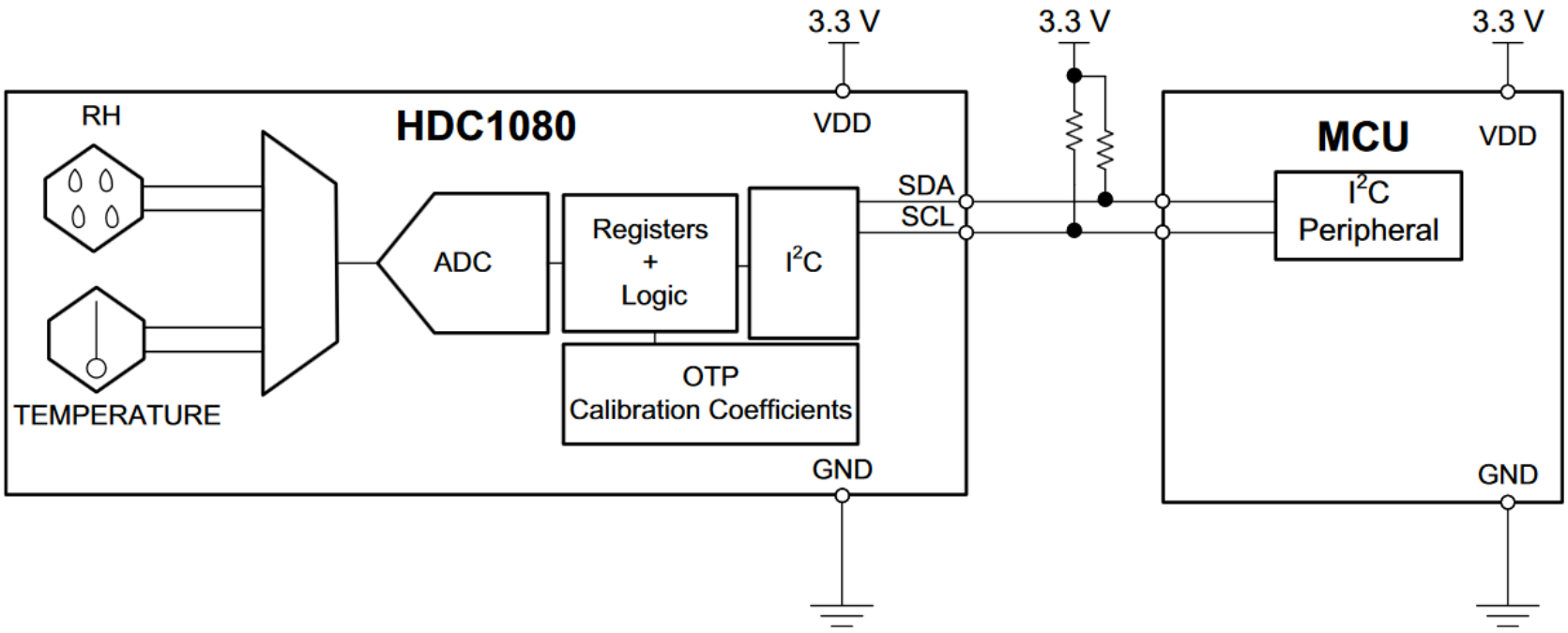
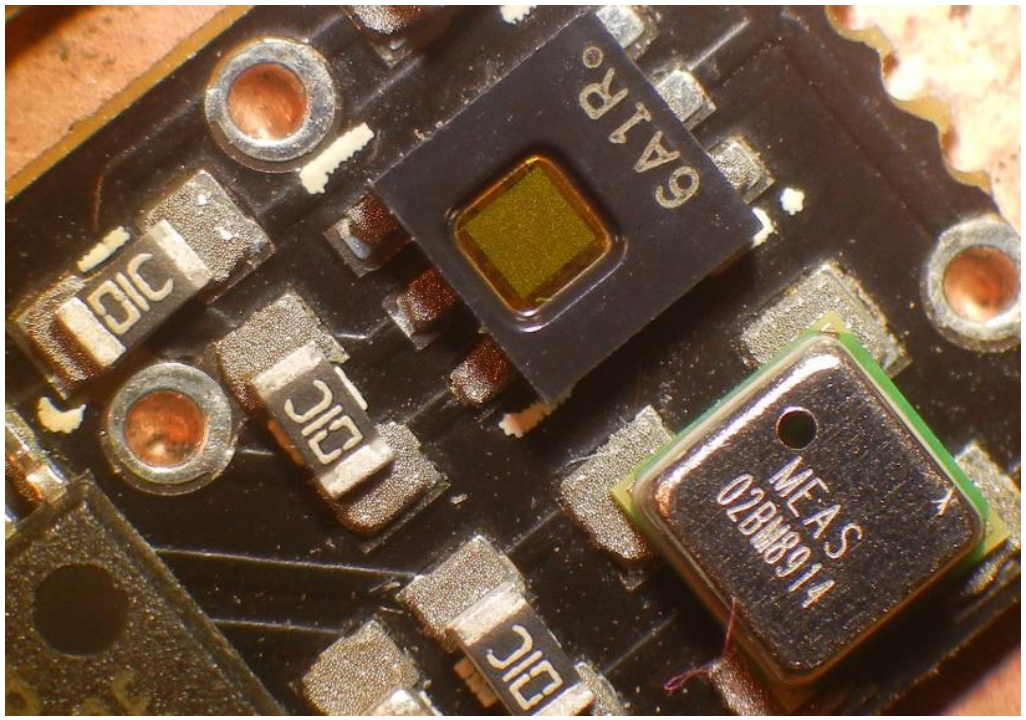


RH, T, p sensor

- Single PCB
- Single serial interface
  - RS 485 or
  - 3,3V UART



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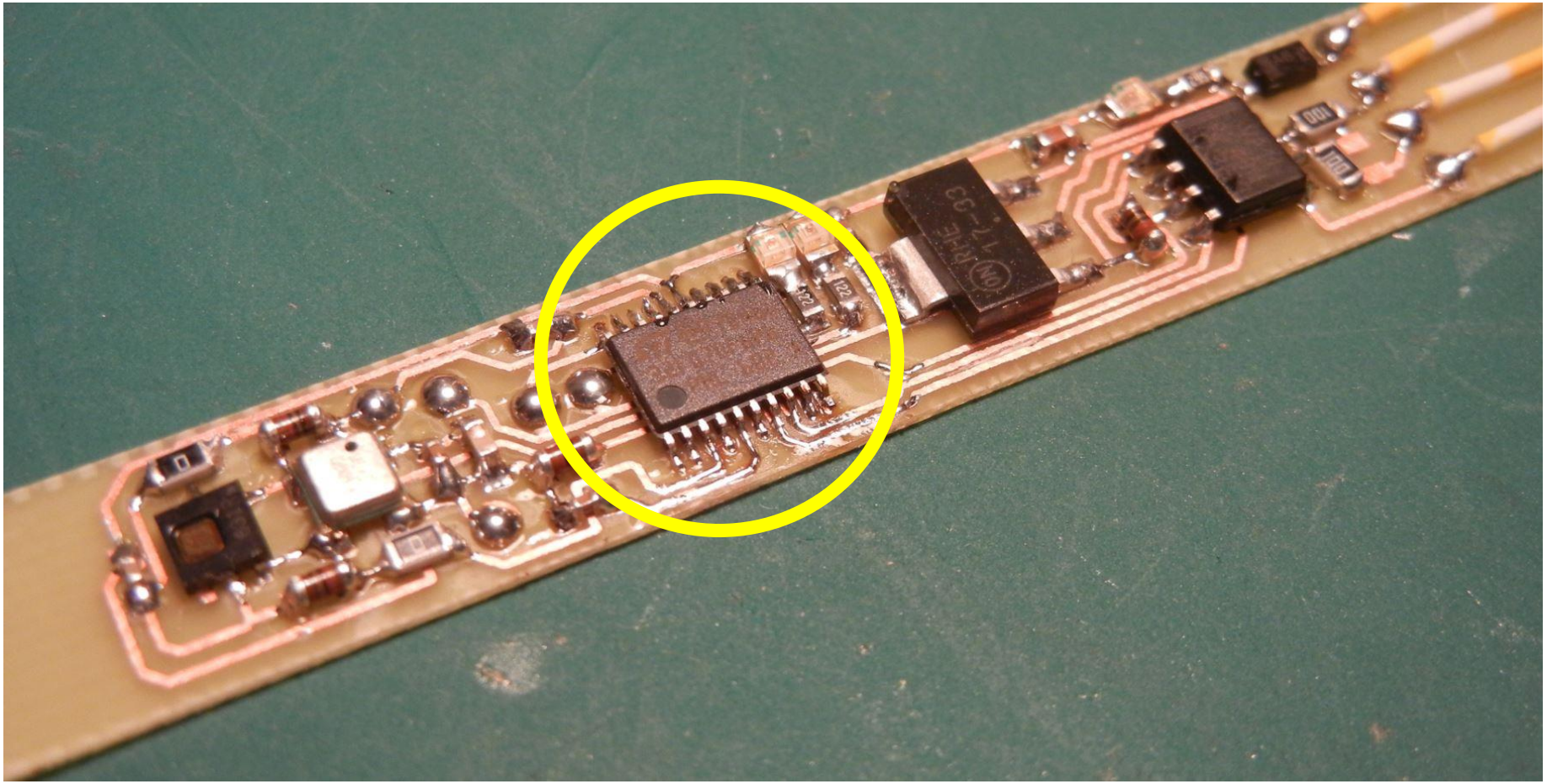
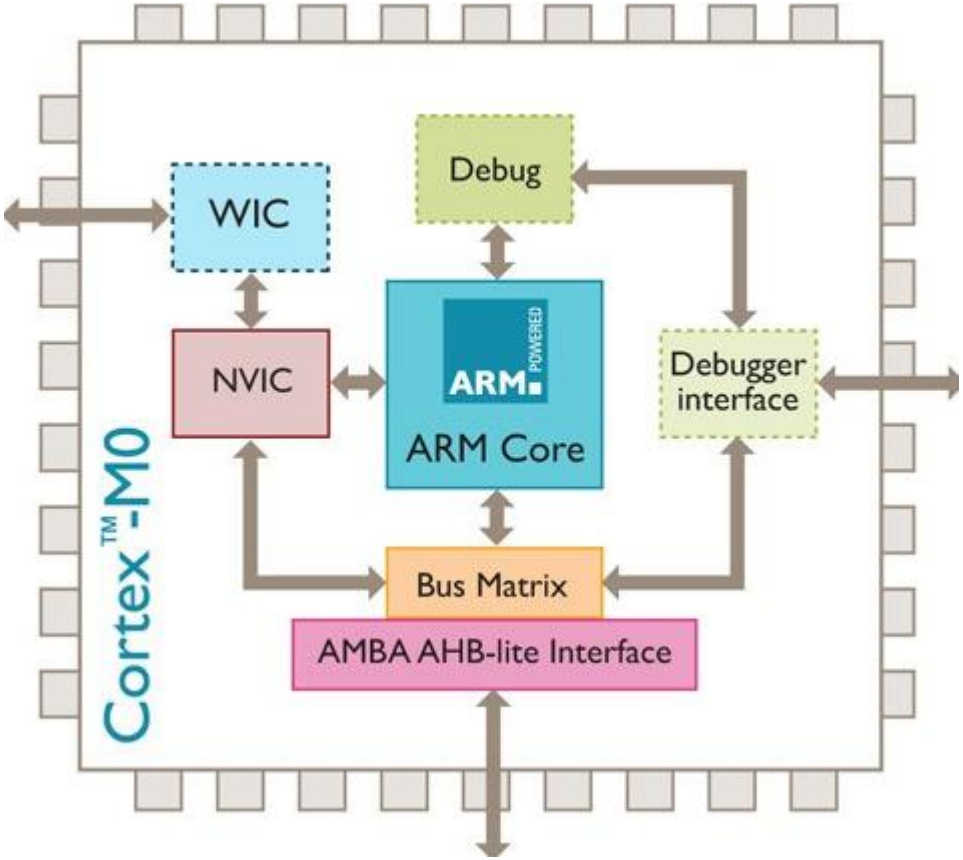
Prototype

- Anyone can do this at home



ARM Cortex M0

- STM32F0
  - low cost
  - cheap
  - 32-bit
  - excellent support
  - big community
  - free / low cost tools
  - in circuit DEBUGGING

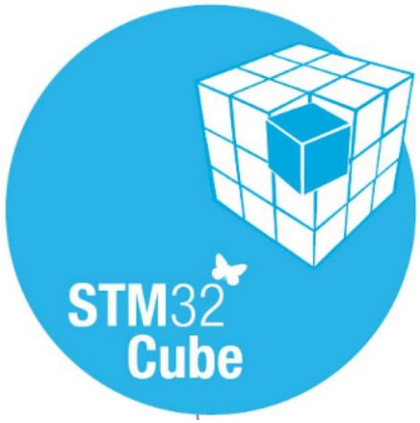


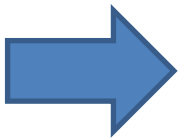
How to
survive without arduino?

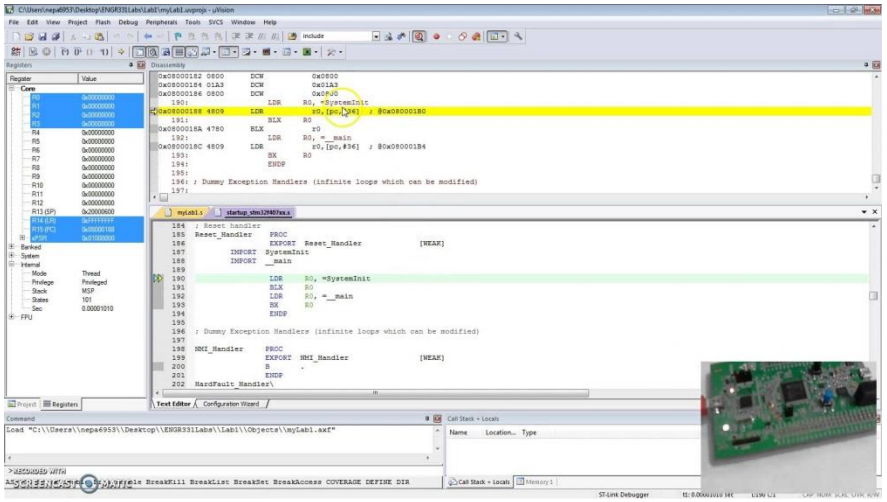
- First, get some knowledge: there **are** µ-controllers which are **not "-duino"**
- Obtain decent dev. board: Nucleo or Discovery kit for STM32F0 (from 0 to 6 EUR)
- Download and activate Keil's free MDK-ARM development environment (a complete, professional IDE)
- Download and install ST’s STM32CubeMX code generator/configurator

Workflow demo

- What you will see:
  - use of project configuration tool (STM32CubeMX)
  - Writing code in Keil IDE for STM32F0
  - Downloading and debugging in target circuit



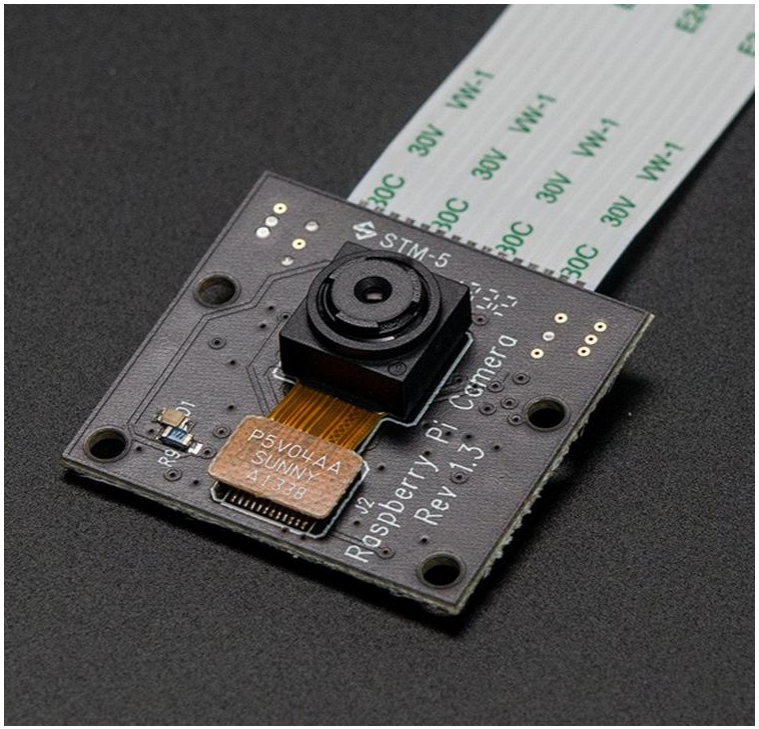


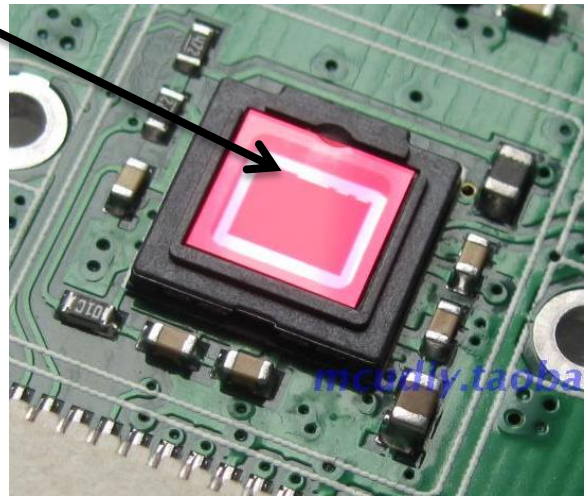


Camera

Raspberry Pi NoIR Camera Board

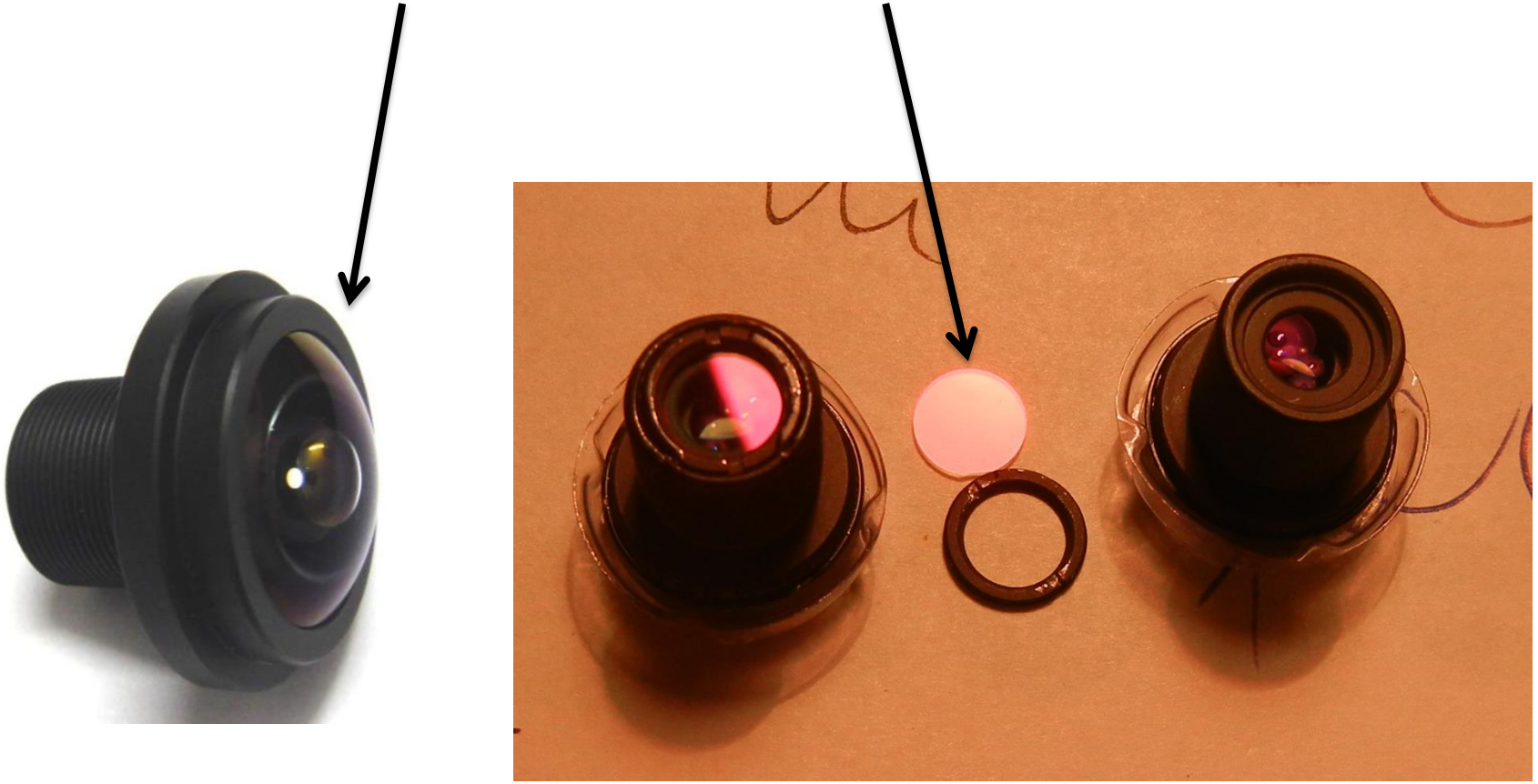
- Small board size: 25mm x 24mm
- 5MP (2592×1944 pixels) Omnivision 5647 sensor
- No IR filter on sensor chip





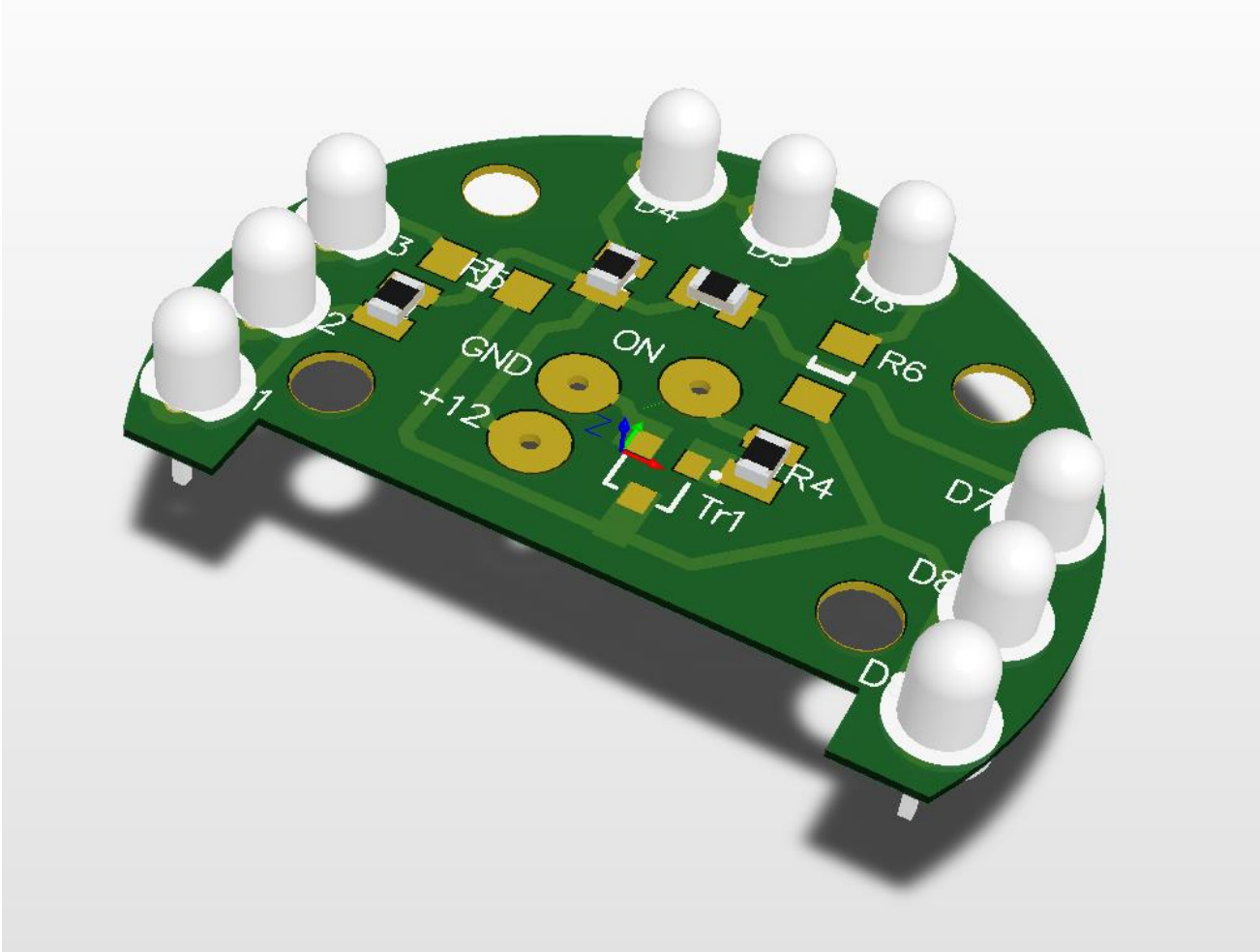
Lenses

Wide angle, without IR filter

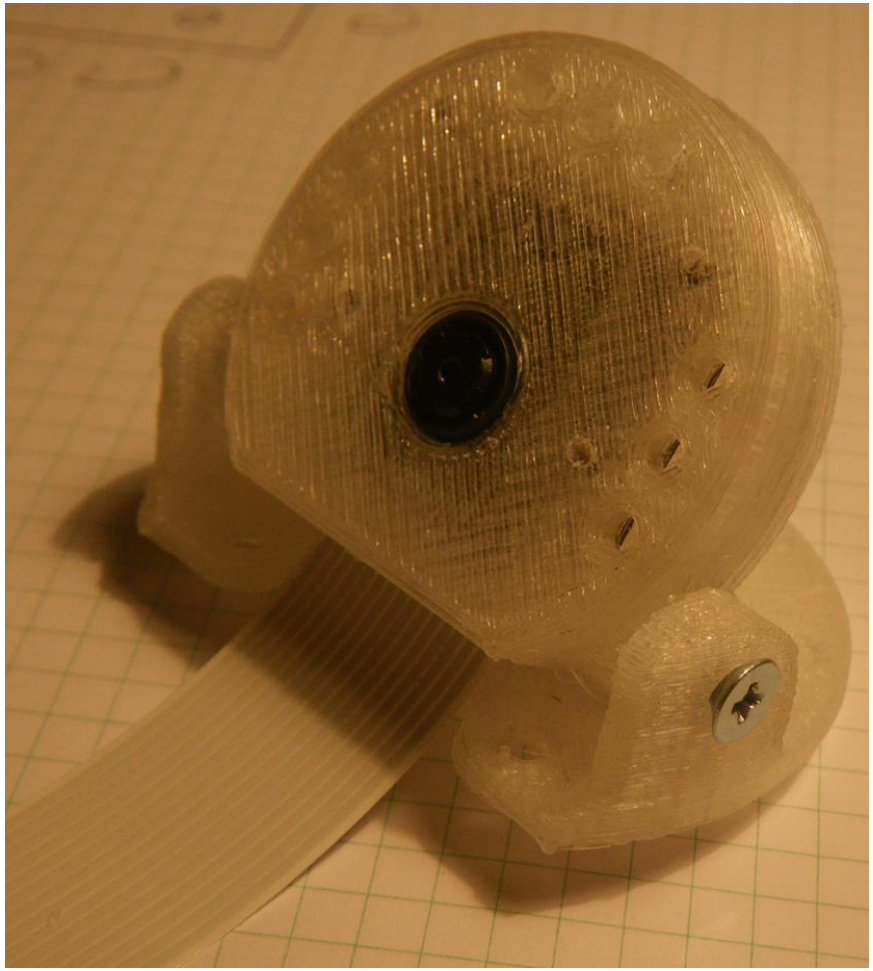


Illumination

- 9 IR LEDs
- Transistor as switch



Camera housing



- 3D printed housing
- compact design
- Adjustable angle

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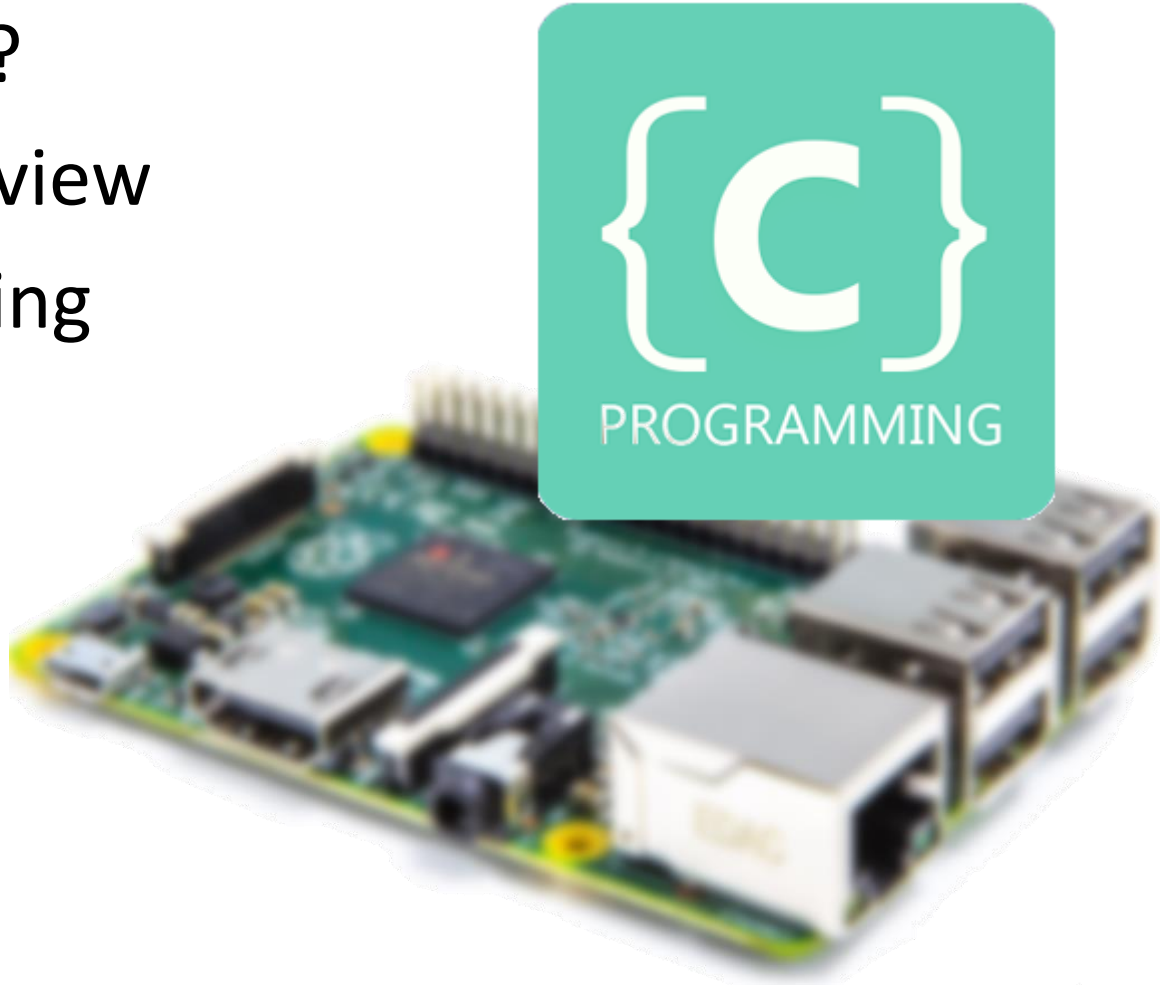
Programming R.Pi in C/C++

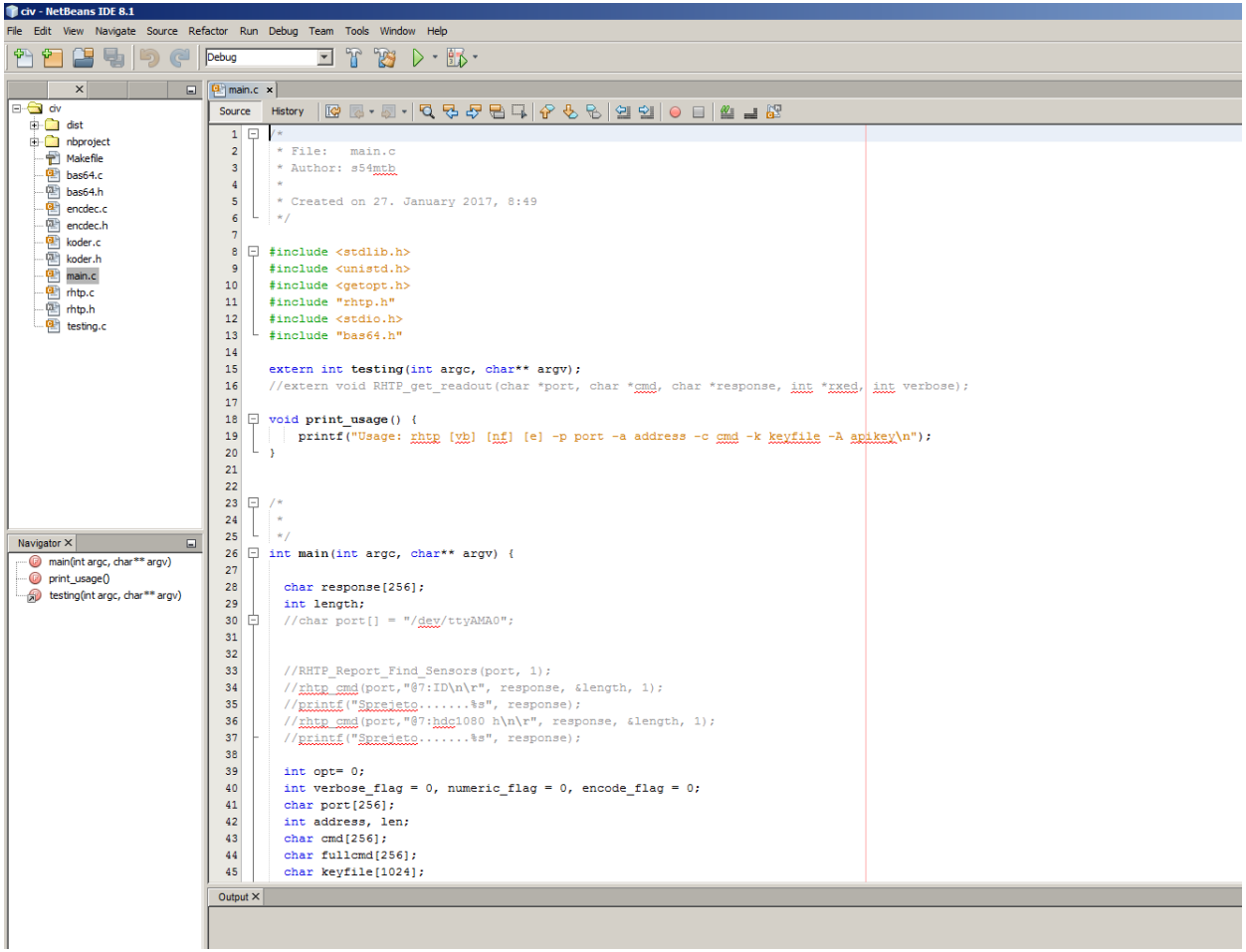
- What is needed?
- Brief setup overview
- Remote debugging
- Example



Programming Your Raspberry Pi From Windows using NetBeans

- Installing NetBeans
- NetBeans Configuration
  - Essential config (setup remote project etc)
  - Personal preference (code completion, Editor preferences, ...)
- Enabling Running Remote Projects in NetBeans
- Creating new project
- Troubleshooting Remote Host Connections

Example (talk to serial device)



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  - Pressure
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  - Sensors
  - Video
- Long range WiFi
- Conclusion
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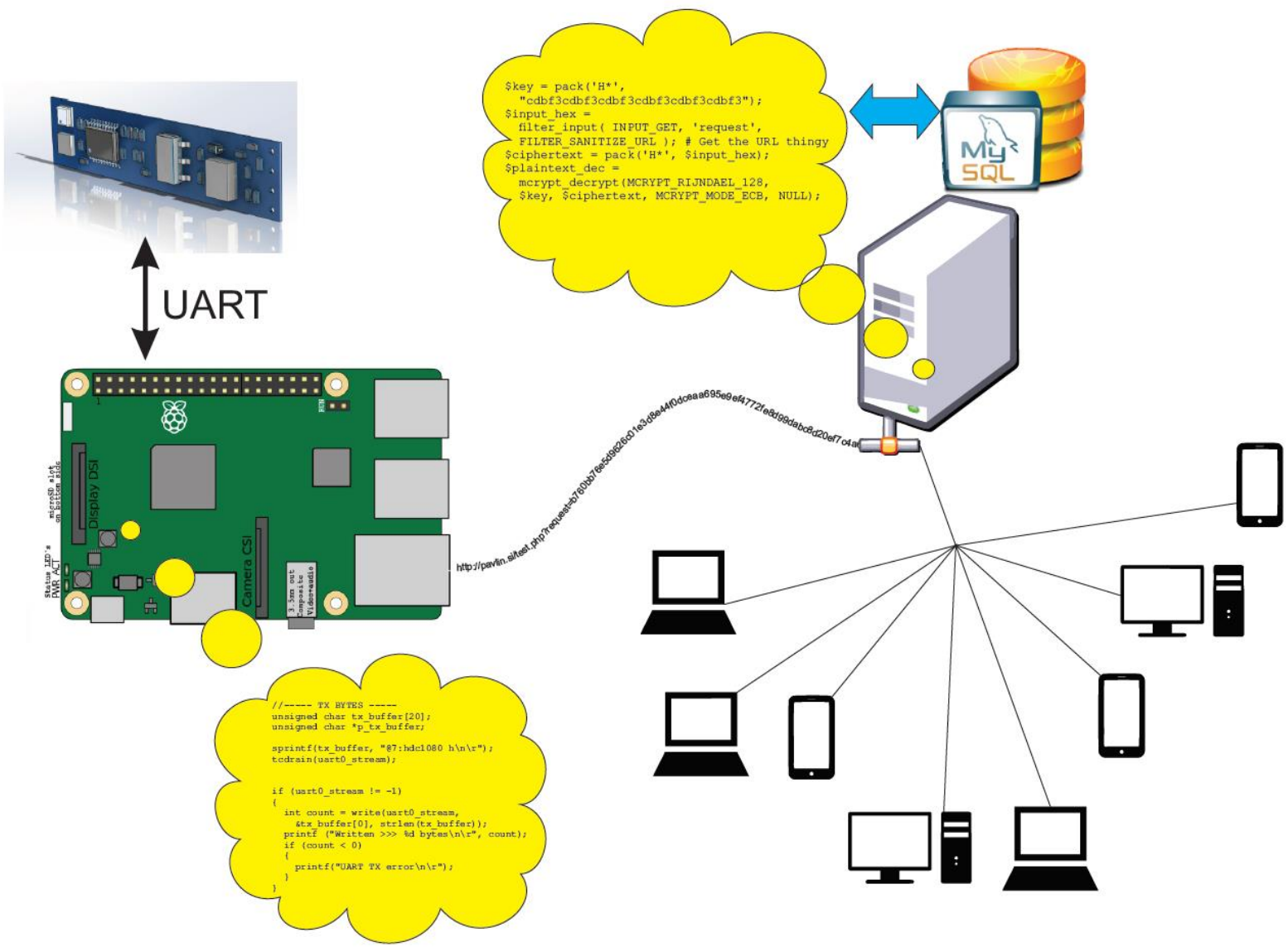
Software - sensors

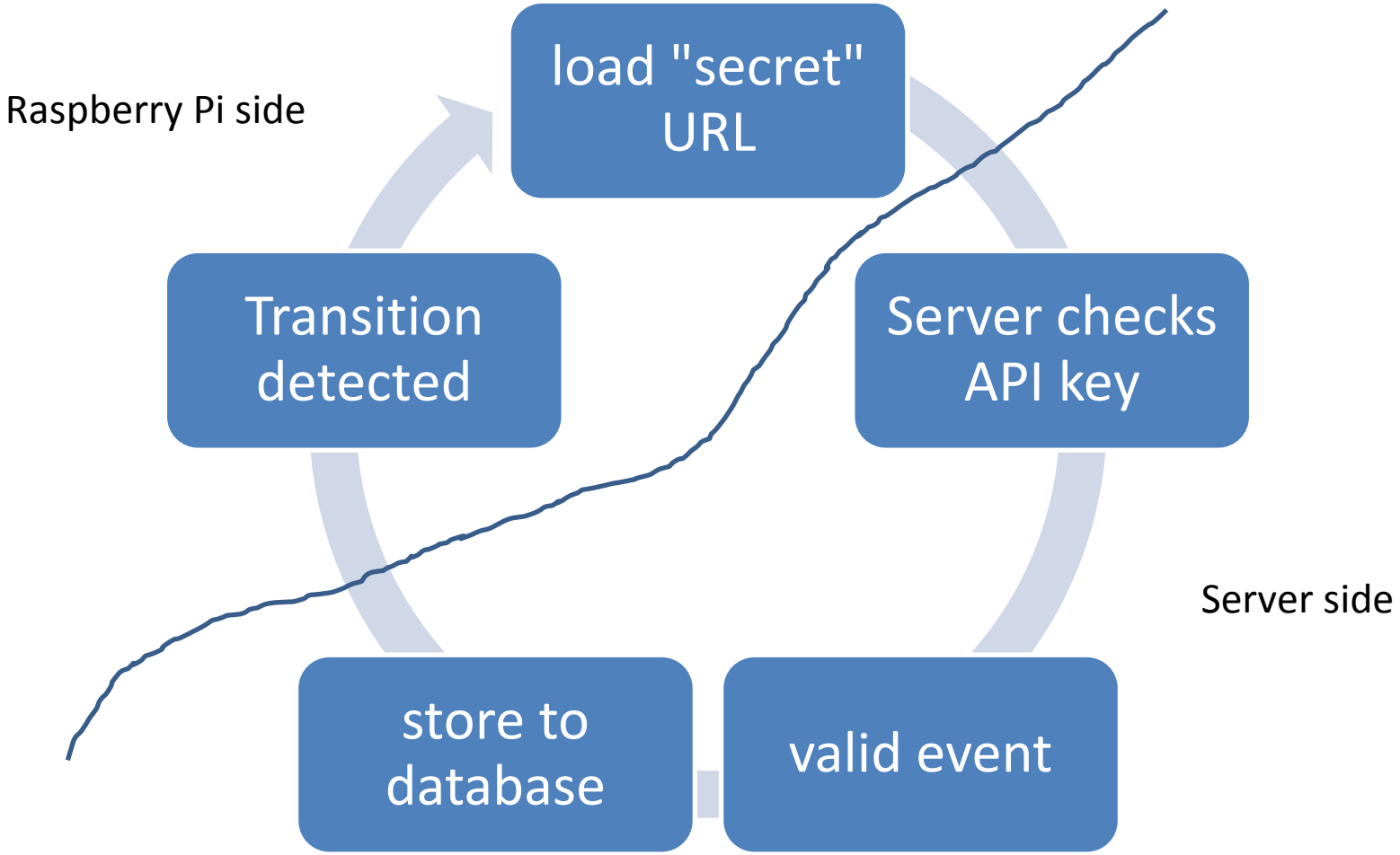


Optical sensor

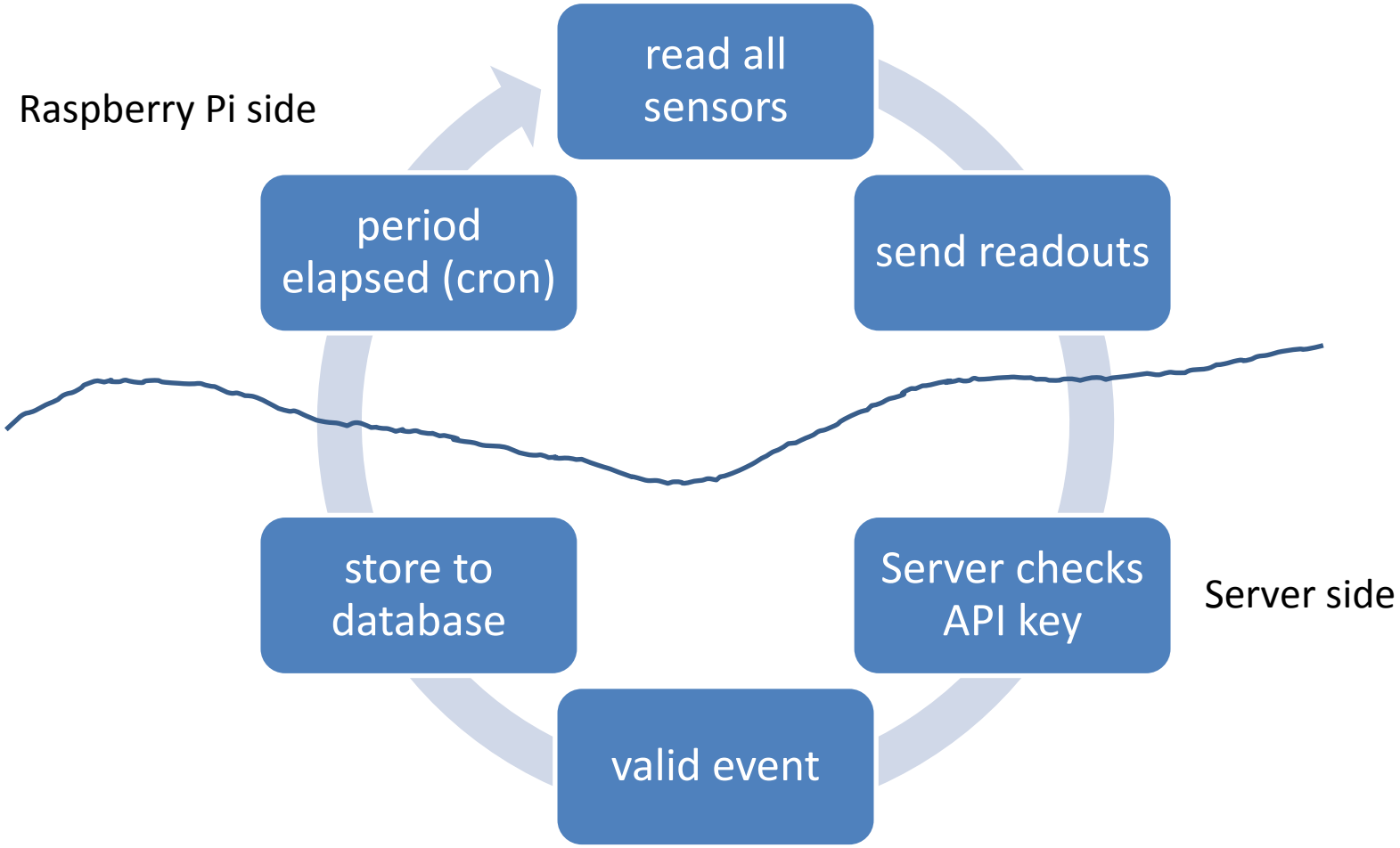
- Shell script periodically checks photodiode pin

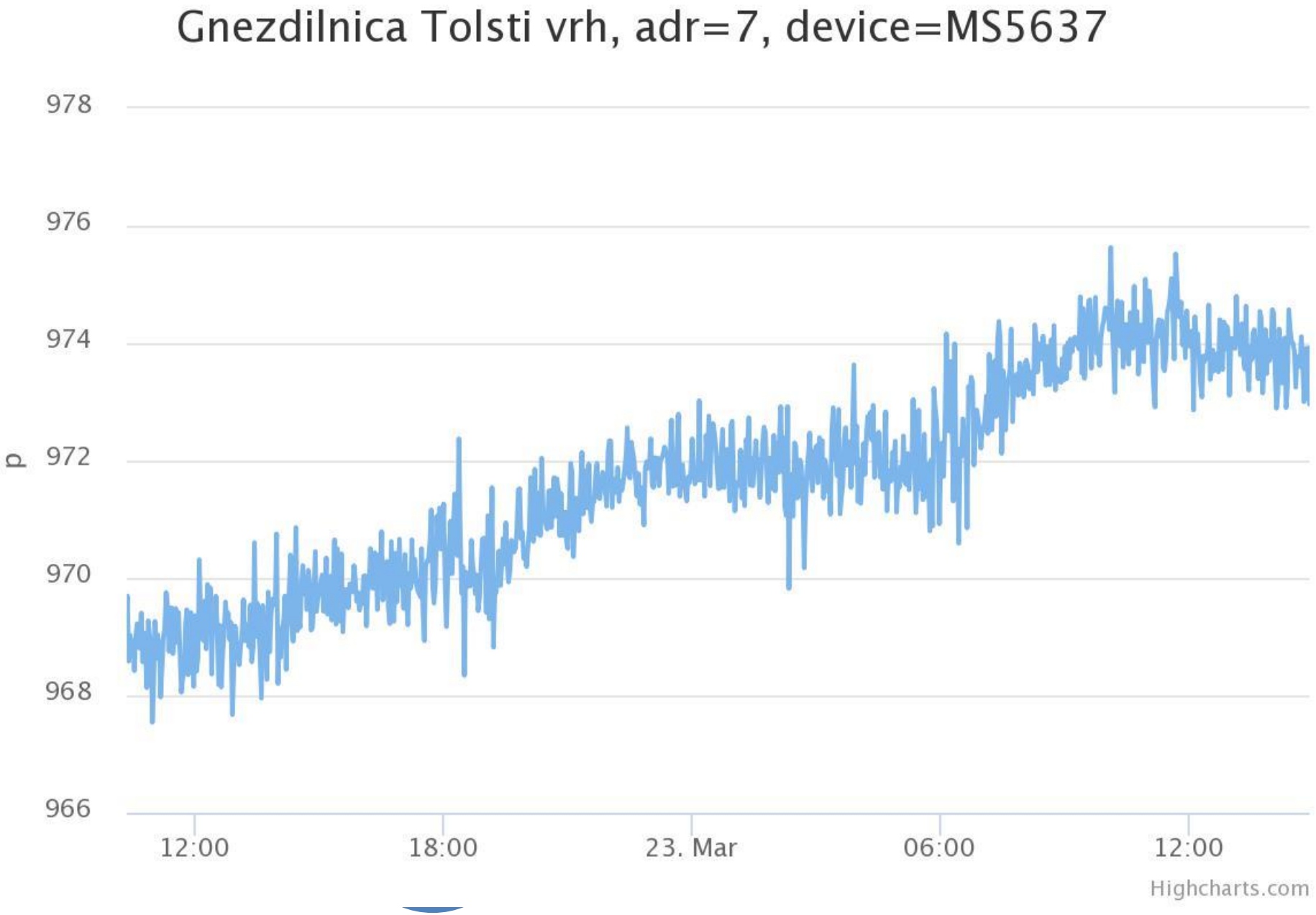
```
#!/bin/bash
apikey=xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
### --------------- Od tu dalje nic ne spreminjaj!!! -----------------
#echo "Najprej init portov"
# IR LED = output
gpio mode 0 out
gpio write 0 1
oldftic=0
while :
do
        ftic=$(gpio read 2)
        if [ "$ftic" -ne "$oldftic" ]
        then
                now=$(date +"%T")
                echo "Sprememba ... $now !"
                wget -q --spider "http://pavlin.si/krozek/dogodek.php?apikey=
                $apikey&address=0&device=PORTAL&parameter=sw&value=$ftic" -O /dev/null
                oldftic=$ftic
        fi
        sleep 0.1
done
```

Optical barrier sensor: what happens?



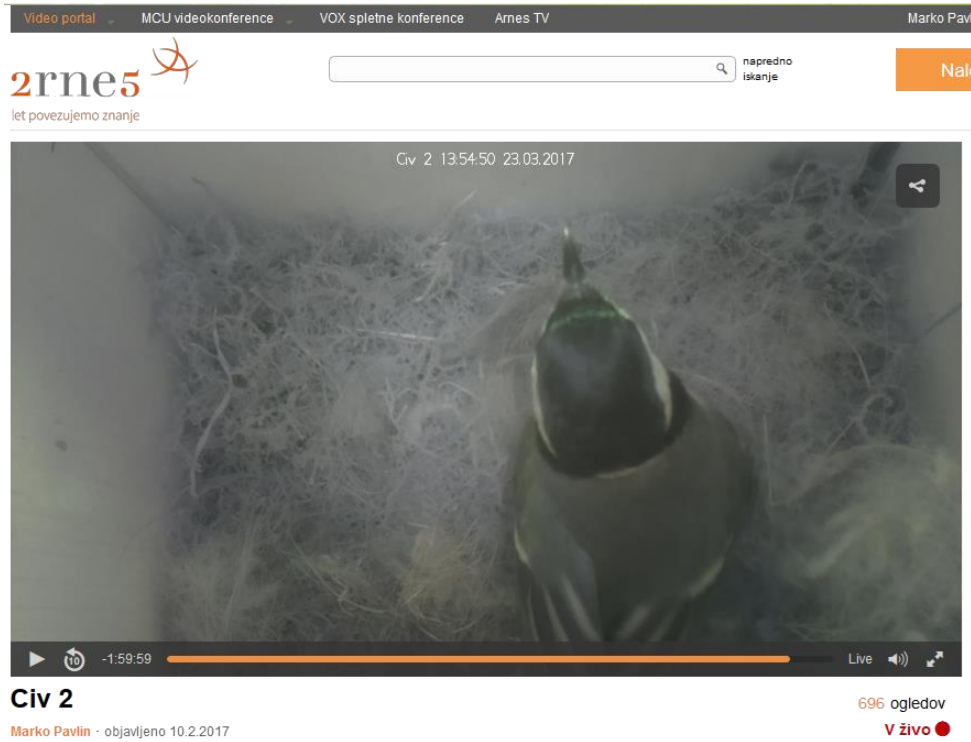
Environmental sensors




Gnezdilnica Tolsti vrh, adr=7, device=MS5637
978
976
974
972
970
968
966
p
12:00
18:00
23. Mar
06:00
12:00
Highcharts.com

Software - video

Camera → RaspiVid → FFMPEG → FLV



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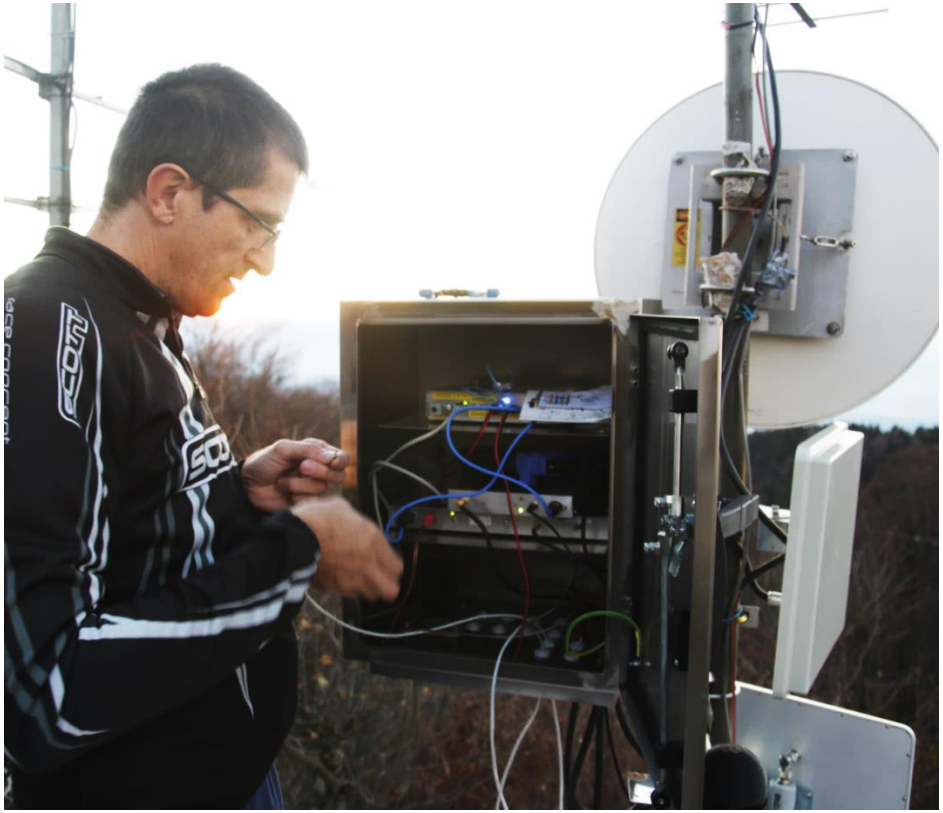
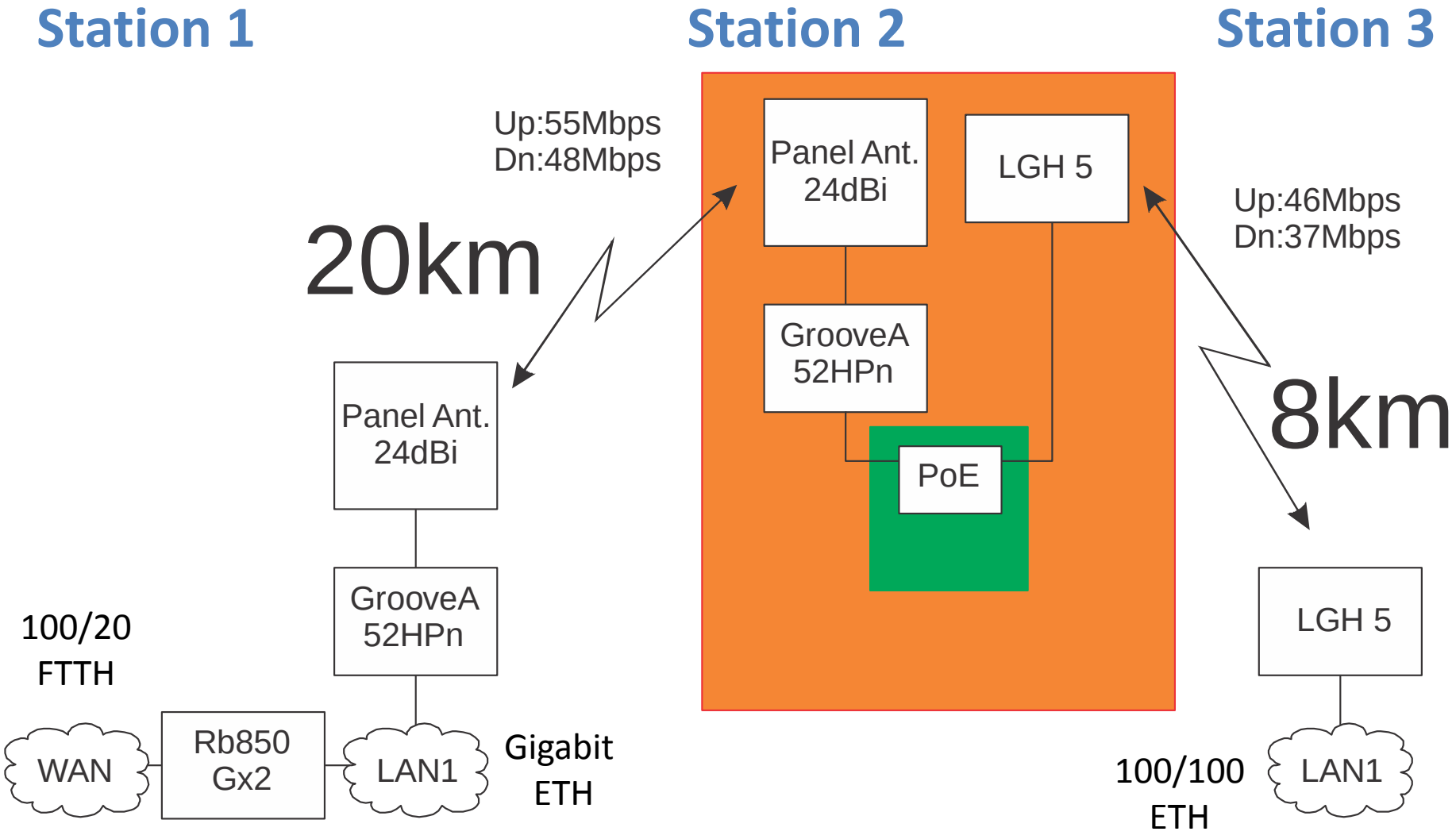
Long range WiFi

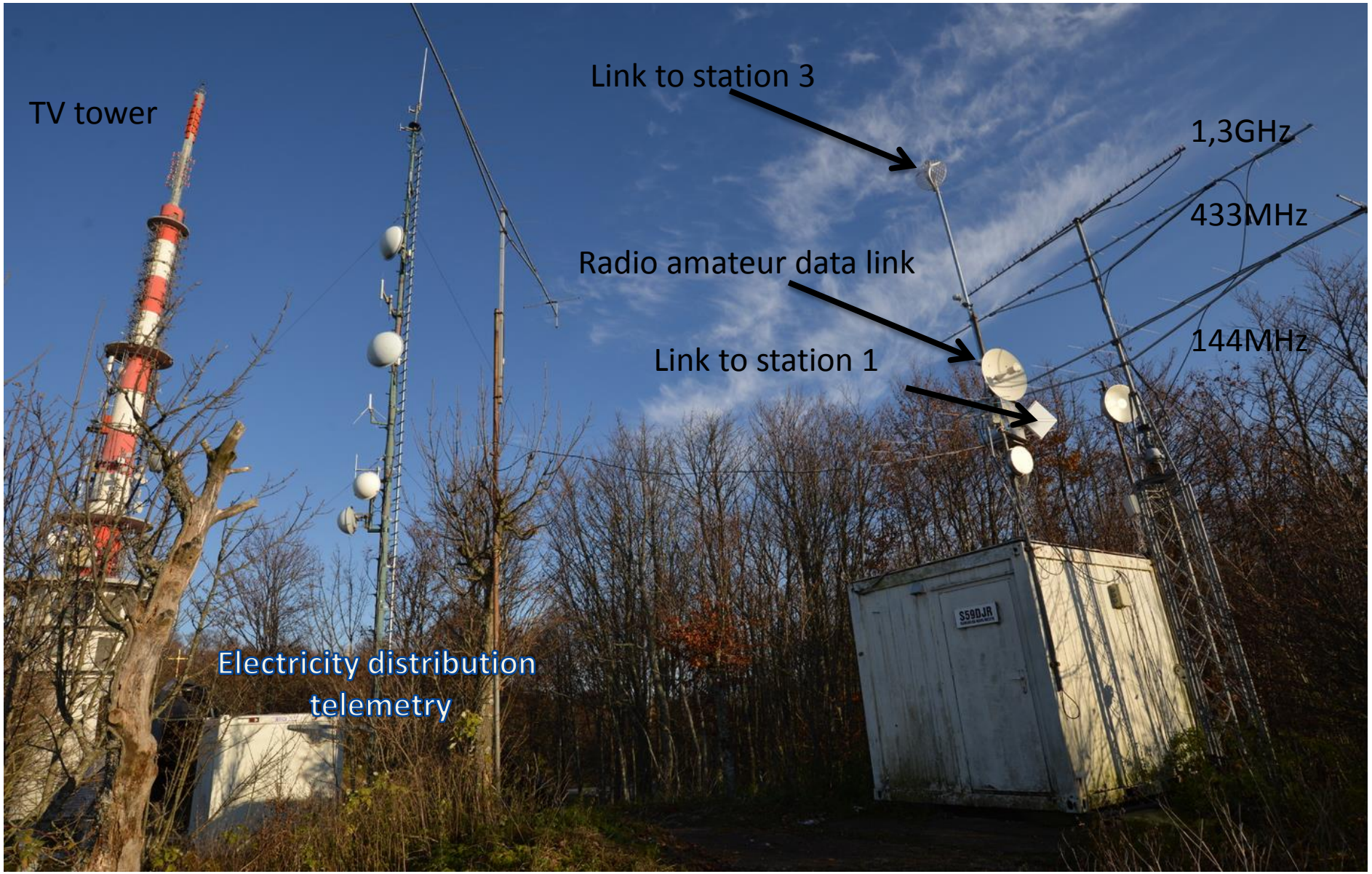
- No LOS : multihop
- Distance more than 15km
- HD video bandwidth
- Secure
- Interference - free
- Low cost
- Stable and reliable



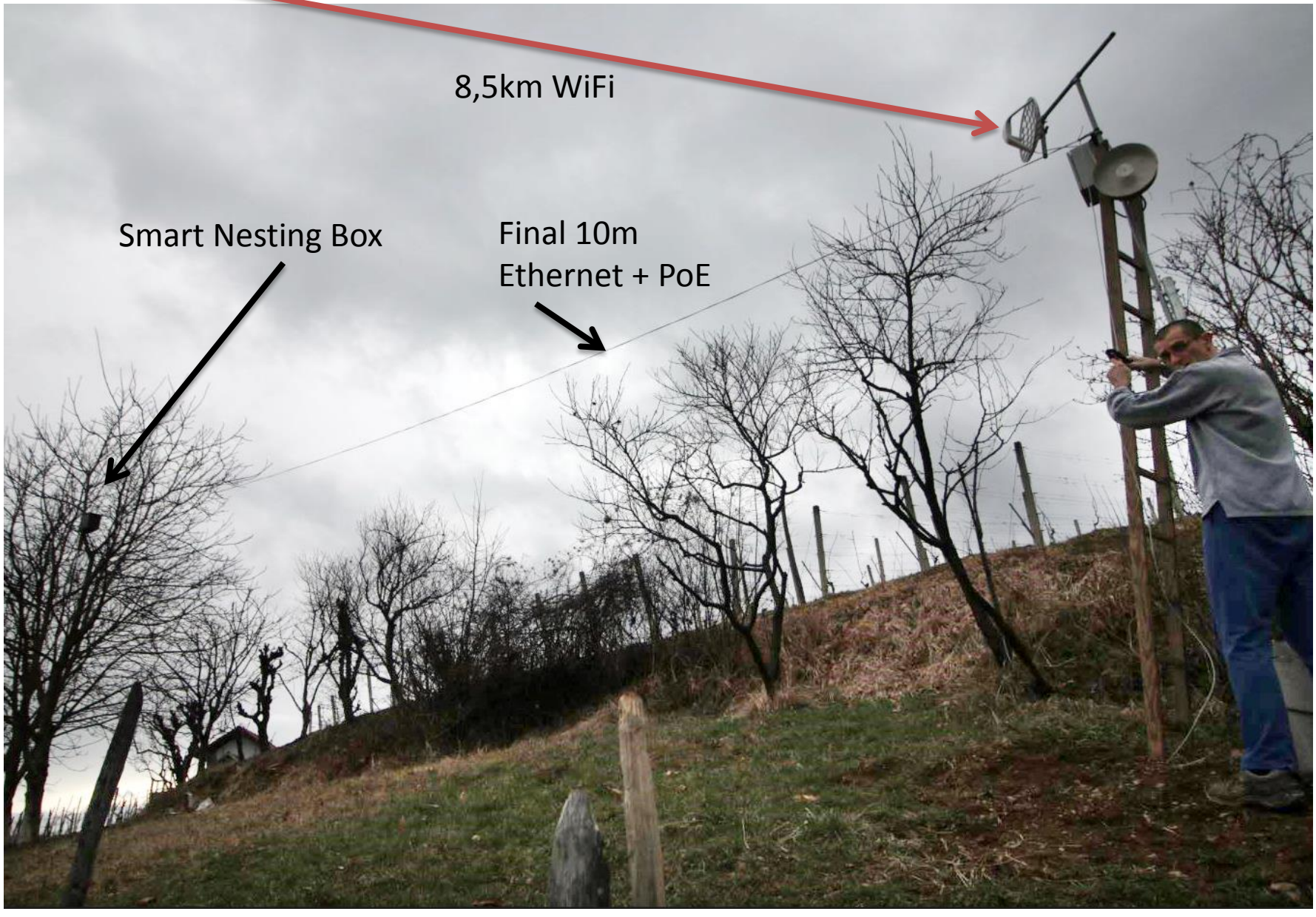
Mikrotik 5GHz W-LAN



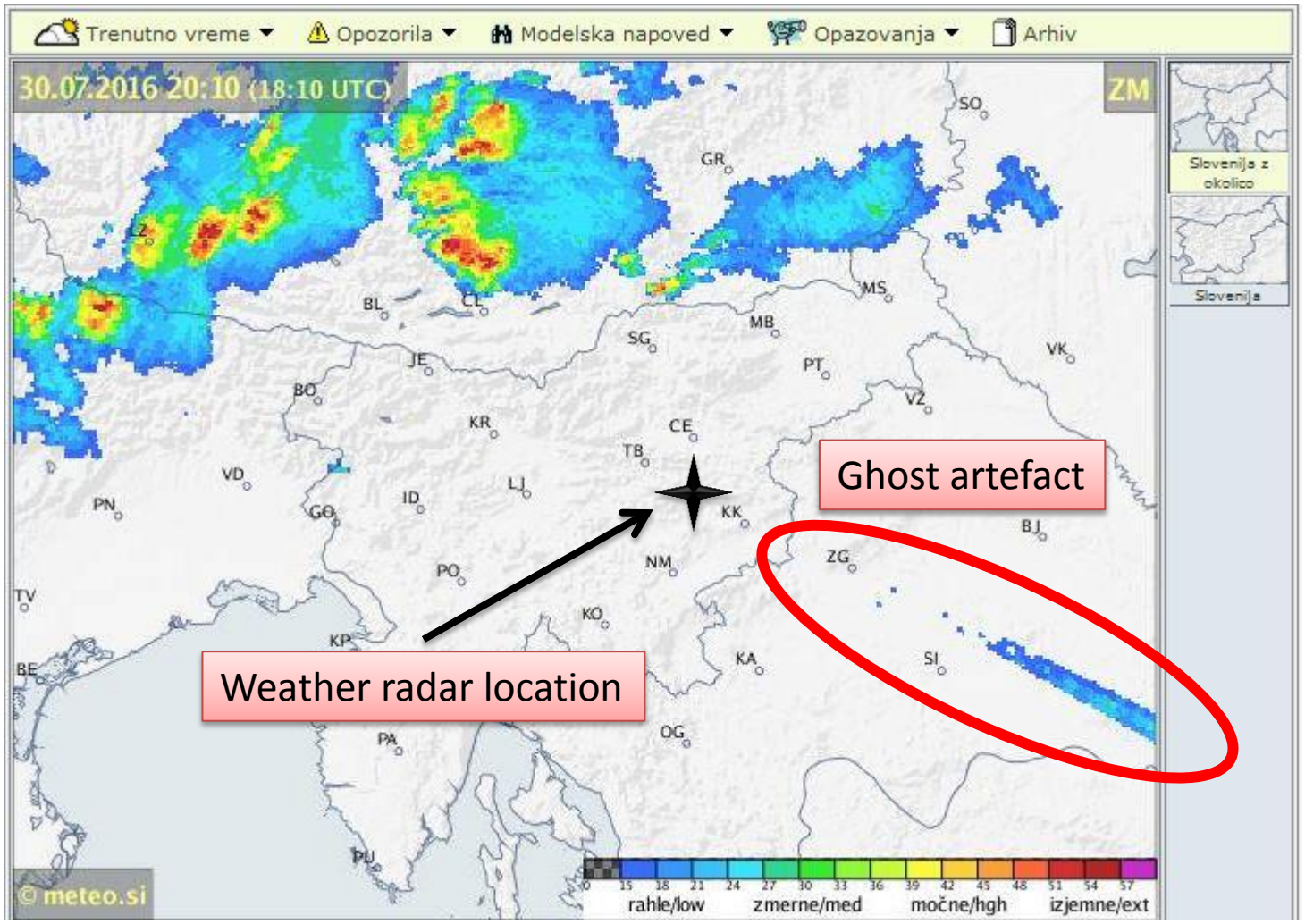
S59DJR > Station 2, 1178 m ASL



Station 3, 330 m ASL

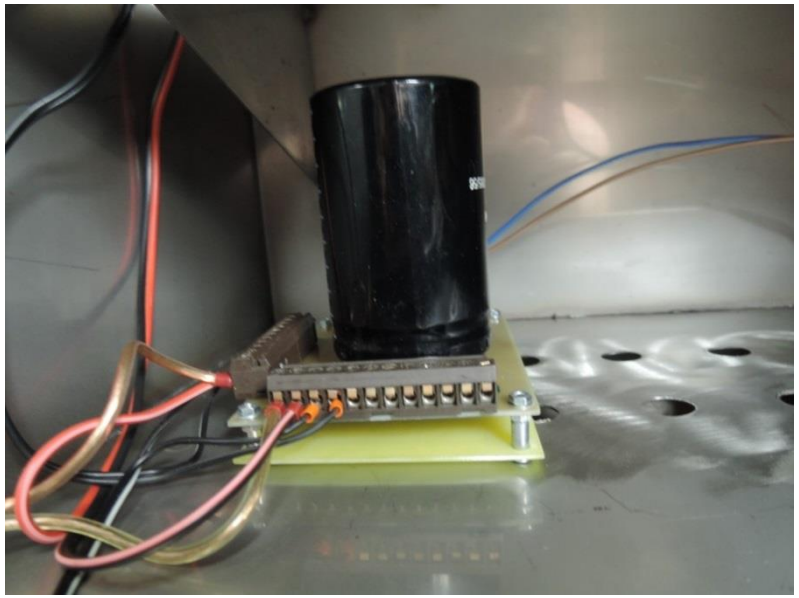


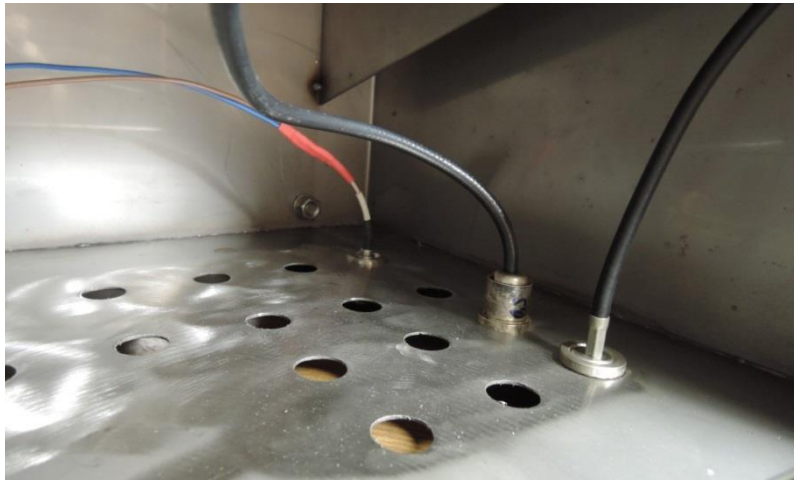
Long range WiFi - interference



Long range WiFi - stable operation

- Metal box
- Coax even for power supply (12V)
- More capacitors
- Transient suppression
- More filters
- Good earth connection
- Periodic hardware reset or alternative link for maintenance access





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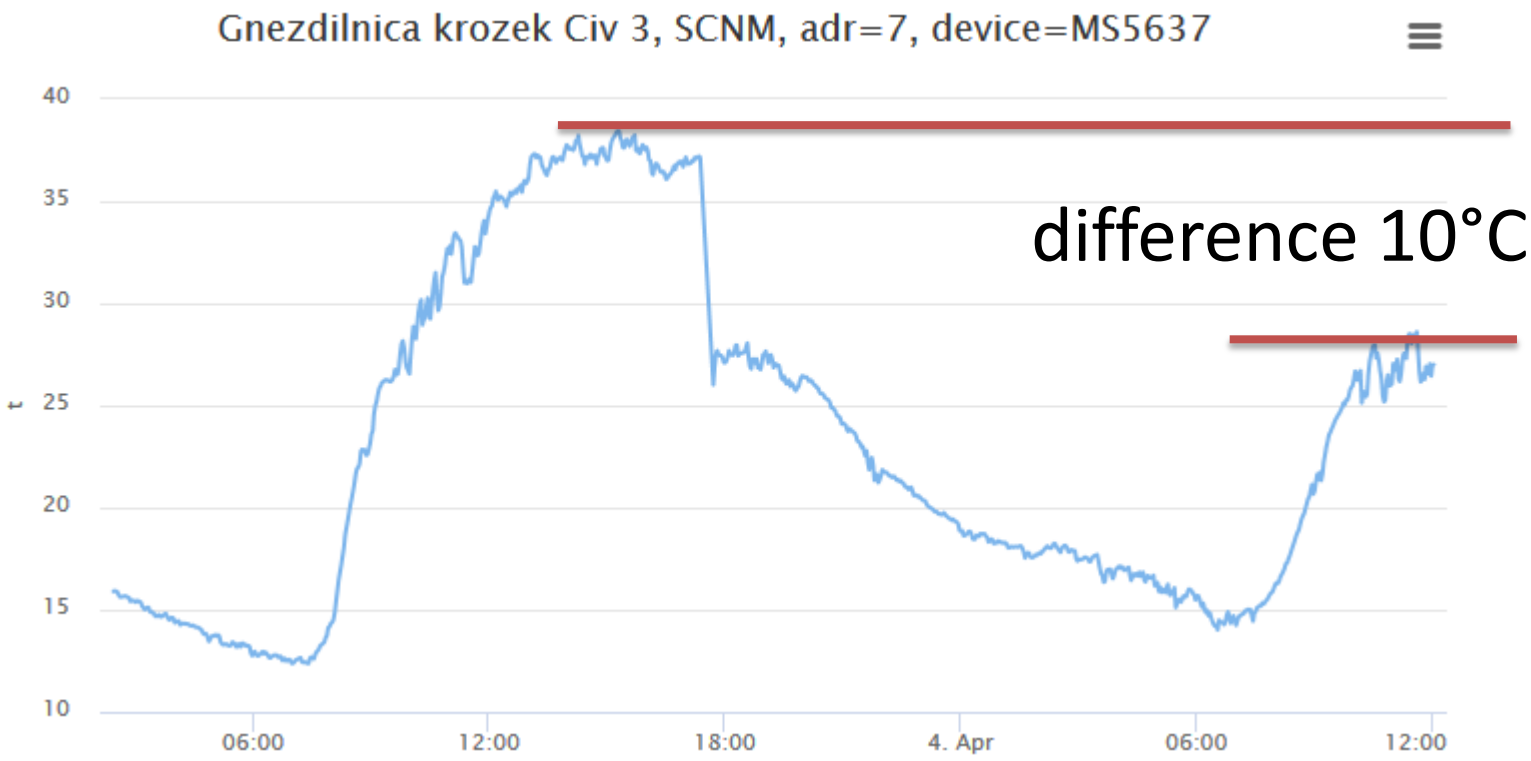
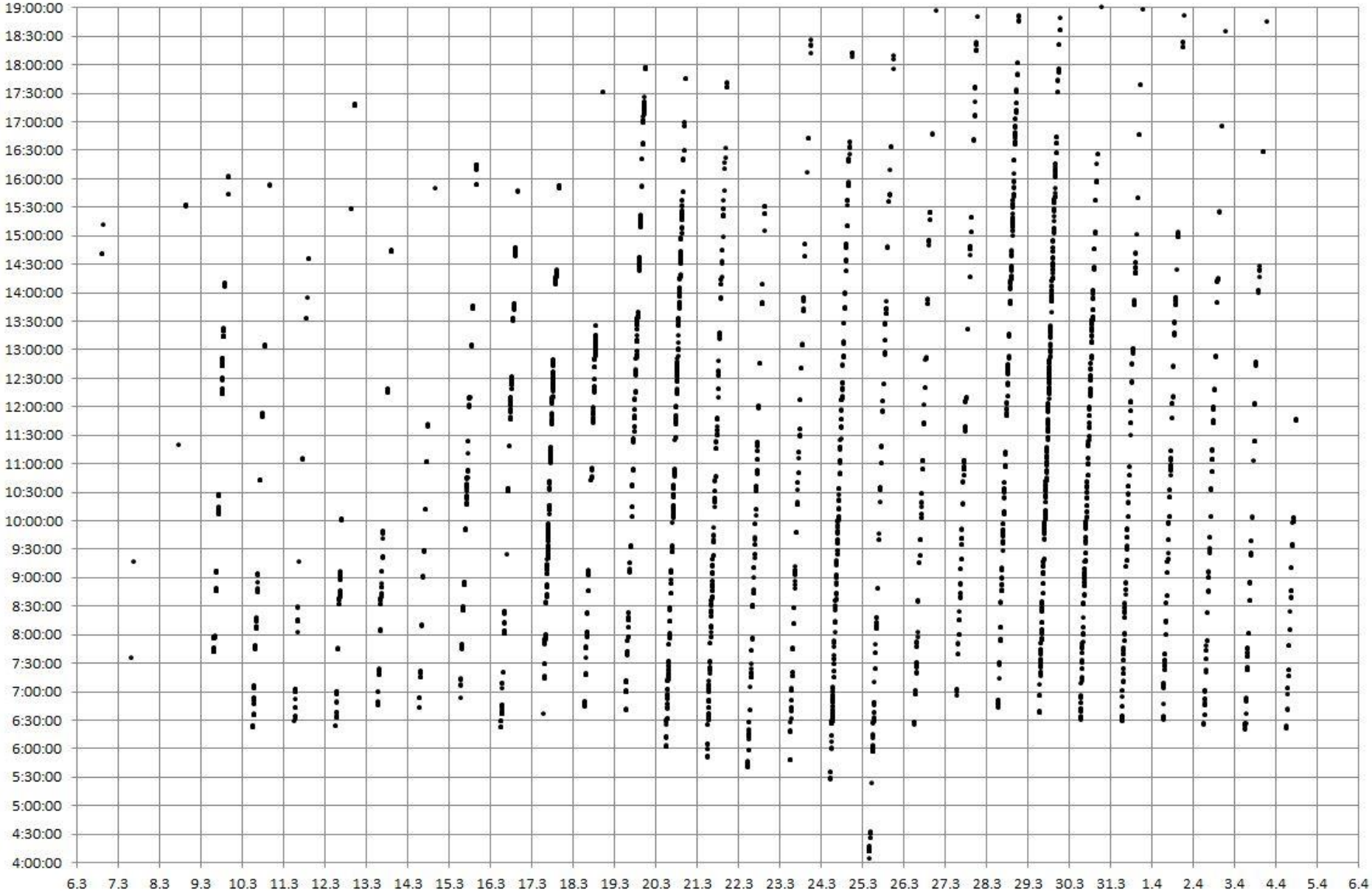
Interesting findings

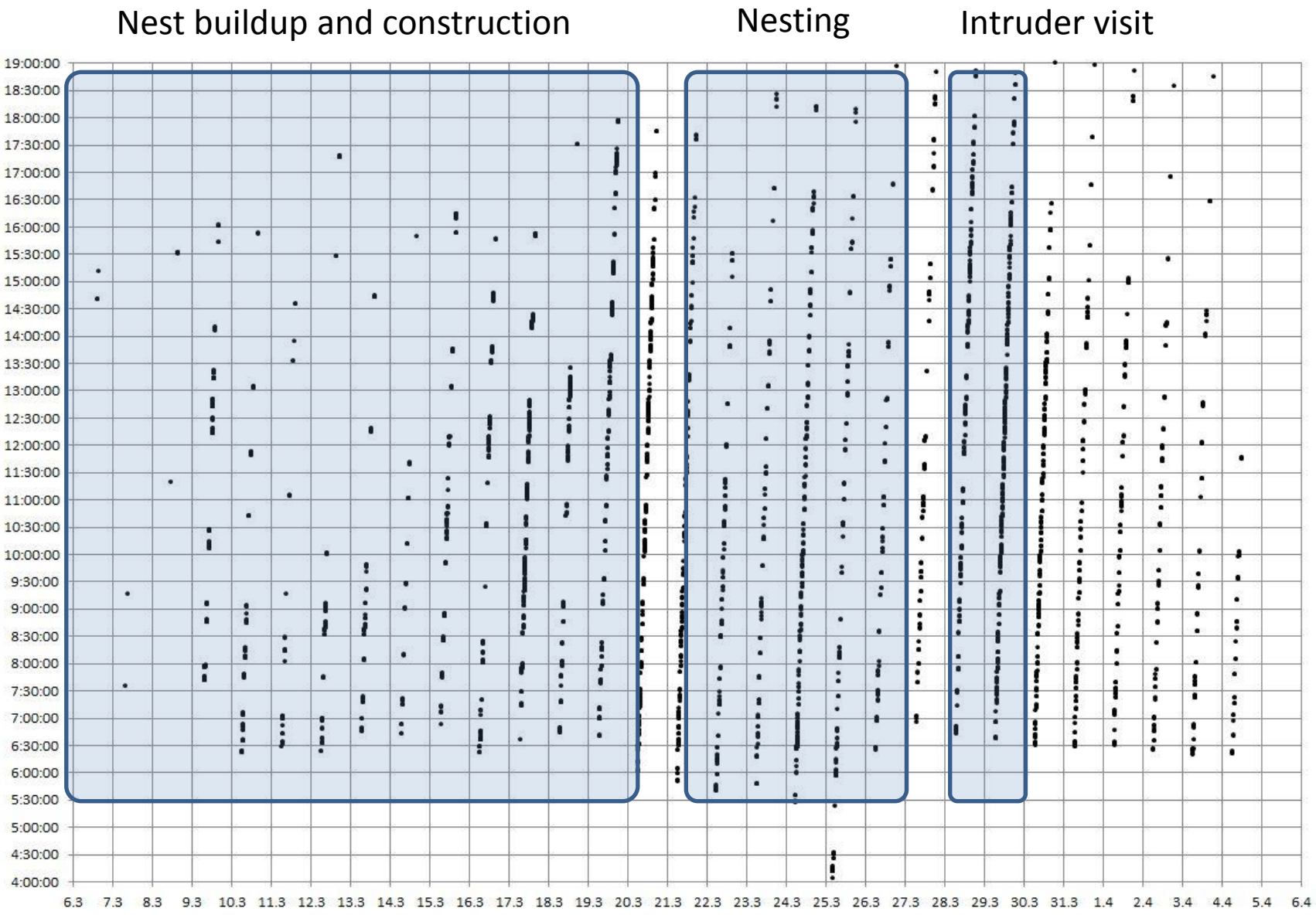
Difference between sun/shadow location



Bird entrance rate

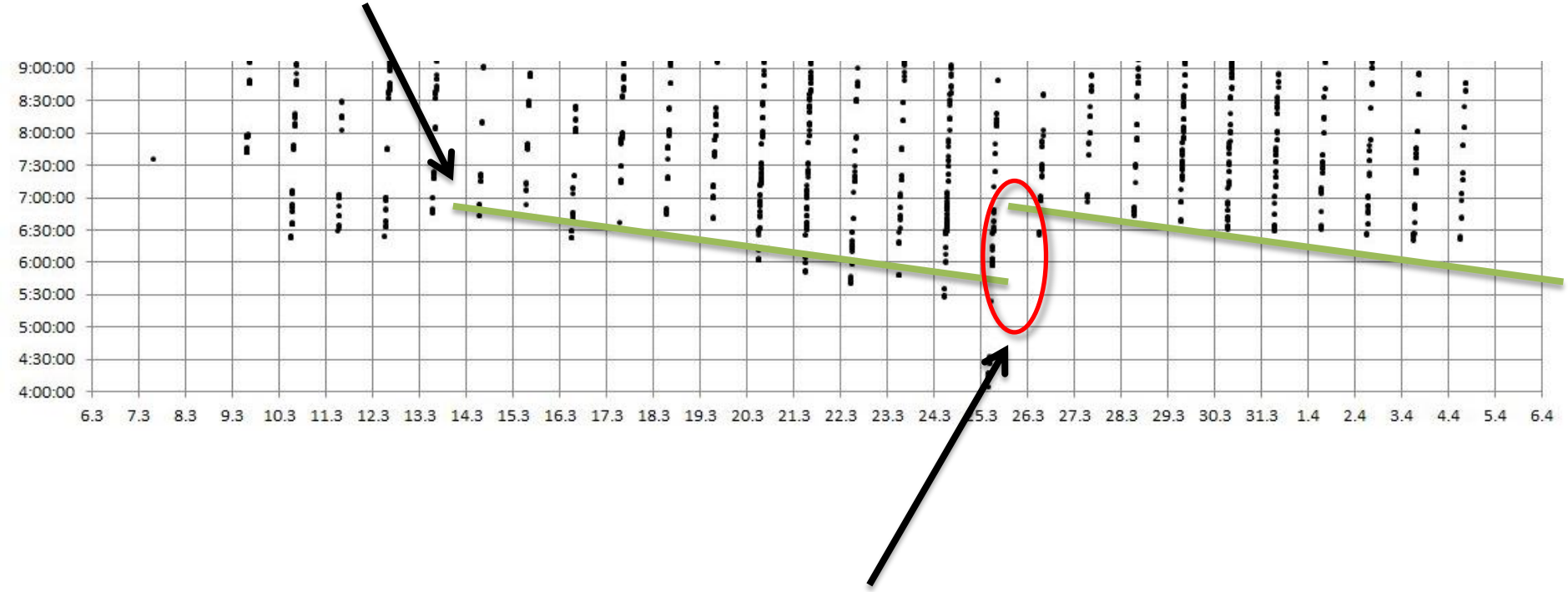


Behaviour patterns



When bird wakes up in the morning?

Not more than 10 minutes difference



Daylight savings: winter to summer shift

Great Tit (*Parus major*)

- Population: 650 million
- nest active period: 20+15+25 days
- Average 60 passes to and from the nest per day

- 32 bit time stamp: 4TB per generation

First visit

Romantic moments

Nest construction

Laying eggs

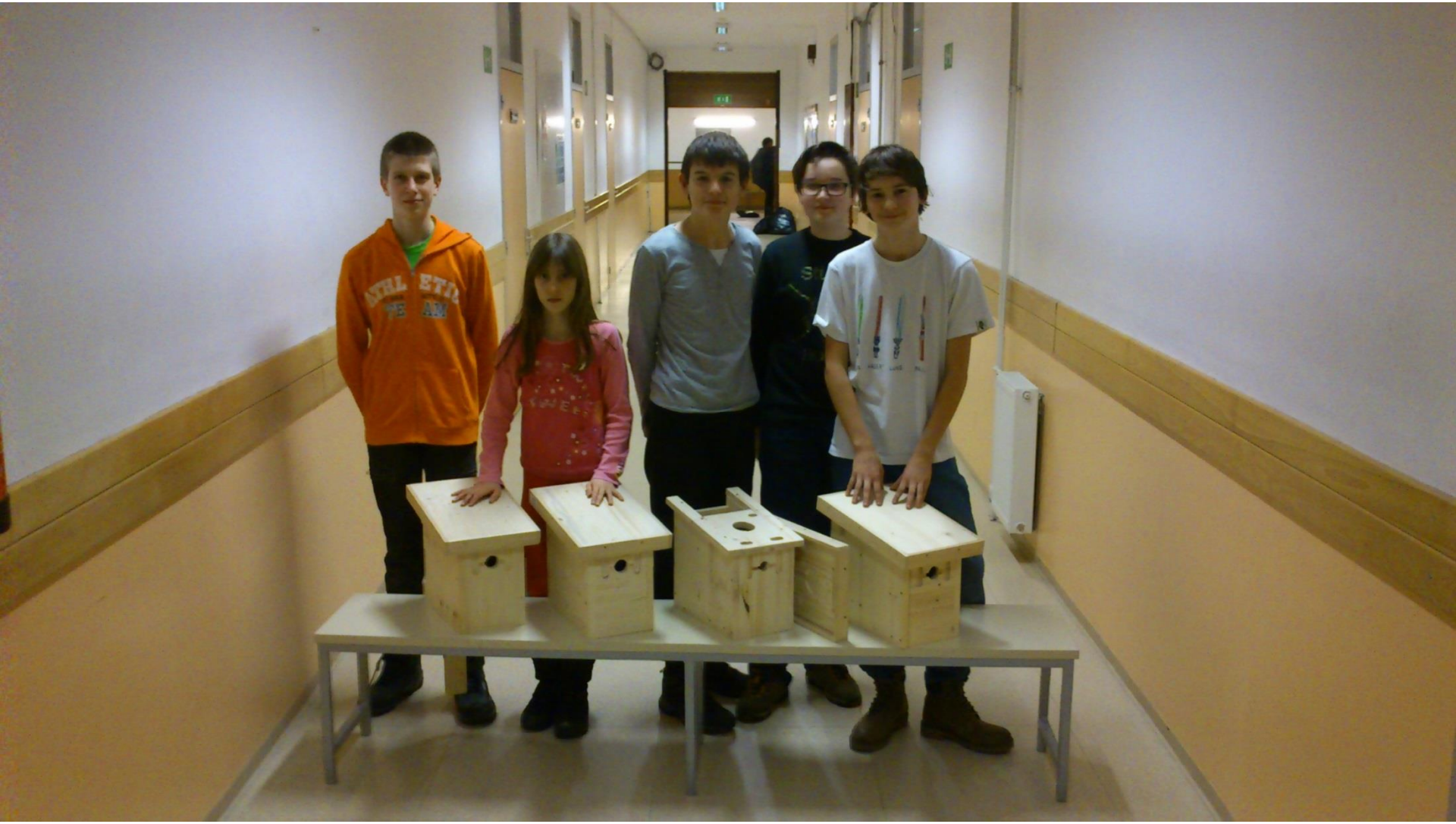
Hatching

Some live action

The Movie

Conclusion

- Interdisciplinary project
  - Contruction, machining, electronics, programming
- Sensors
  - Light, camera, environment
- Live connection
  - Sensors, video feed
- Improvements
  - sound, motion, weigh scale, illumination, external sensors



Future plans

- Share the knowledge
- Help interested groups to rebuild same or similar projects
- Redesign electronics
  - cheaper, smaller, more "integration friendly"

Thank you for your attention