Project Quadcopter

Construction, calibration and modification

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Table of Contents

Goals

Design and construction of a quadcopter

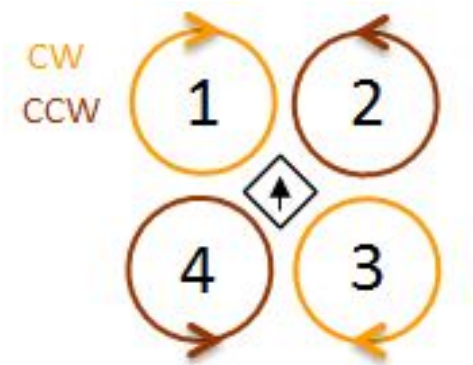
- Further goal: autonomous obstacle detection with Microsoft Kinect

Hardware and construction

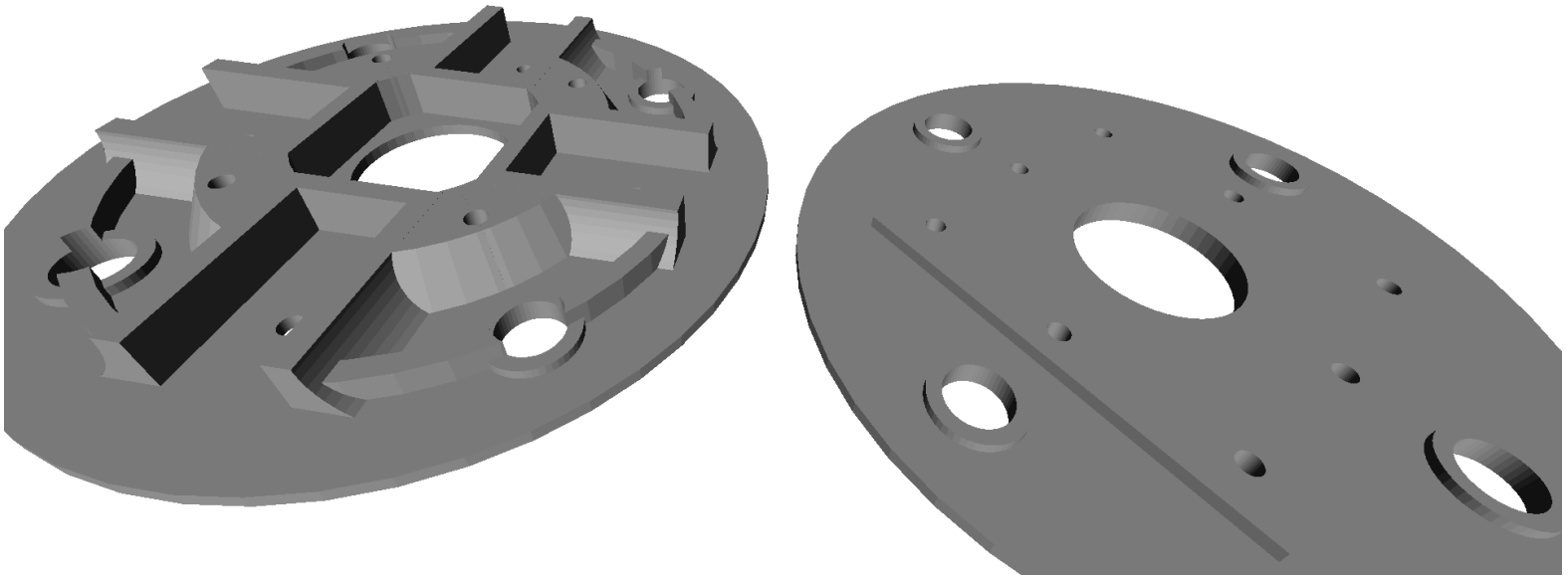
Frame

- AeroQuad Cyclone frame

- Quad X configuration



New frameplates 3D-plotted

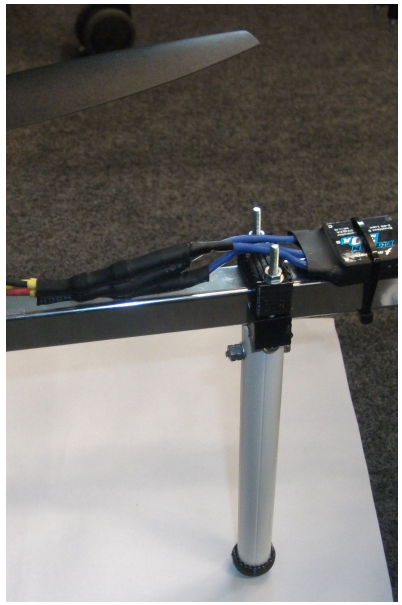


- Designed new frameplates
- More stability, replaceability

Landing gear

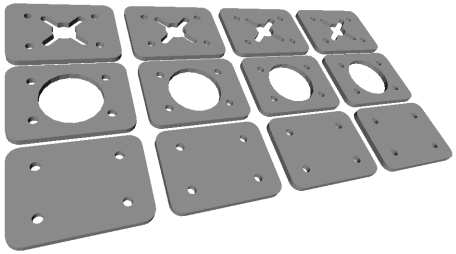
- Temporarily upgraded footings

- New stable gear
- Easy replacable



Motor attachement

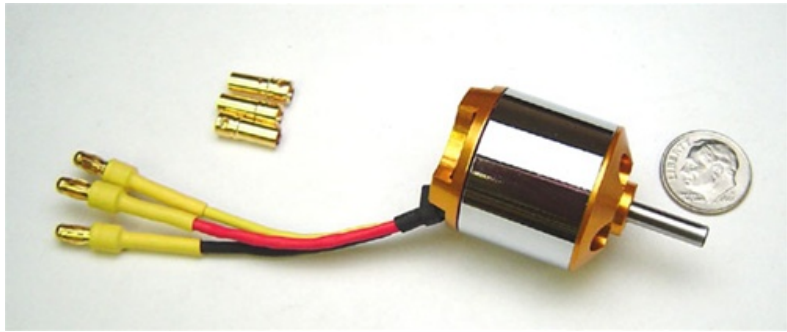
- Most replaced part
- Motors need to be parallel to z - axis



- High heat development
- Washers used to transport heat
- LEDs added for orientation

Motors and Electronic Speed Controllers (ESC)

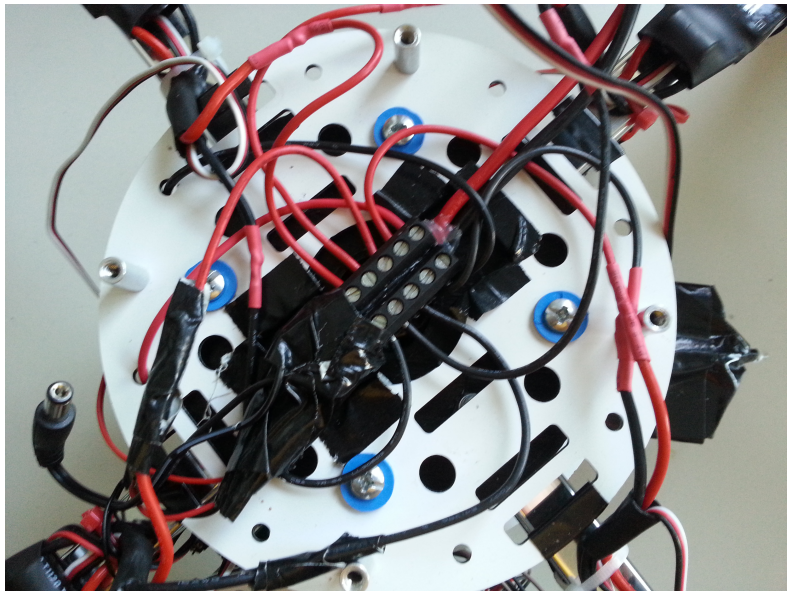
- 4 x A2217-9 brushless motor
- 950 RPM/V
- 10x4.7 propellers
- 12x4.5 propellers



- 4 x brushless flyfun ESC 30A

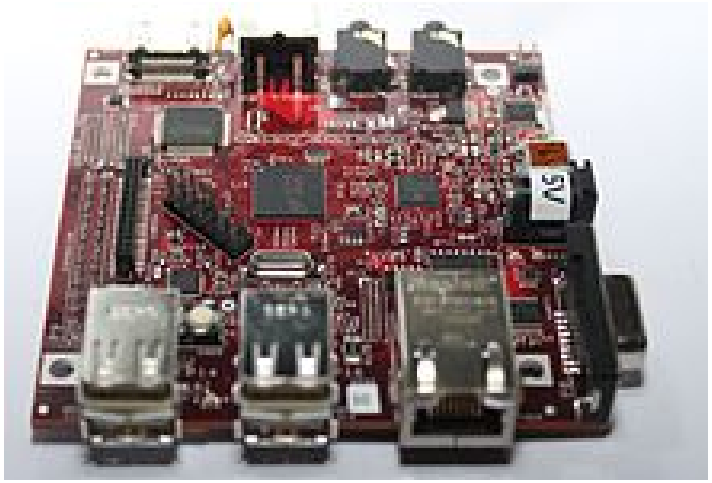
Battery and power distribution

- 3 cell LiPo battery(11.1V 25C/50C) providing 10min flighttime
- Power distributing to ESCs, LEDs, Arduino board and under voltage protection



- High resistance at clamping block
- Weak connection with tamiya connector
- Changed to traxxas connectors

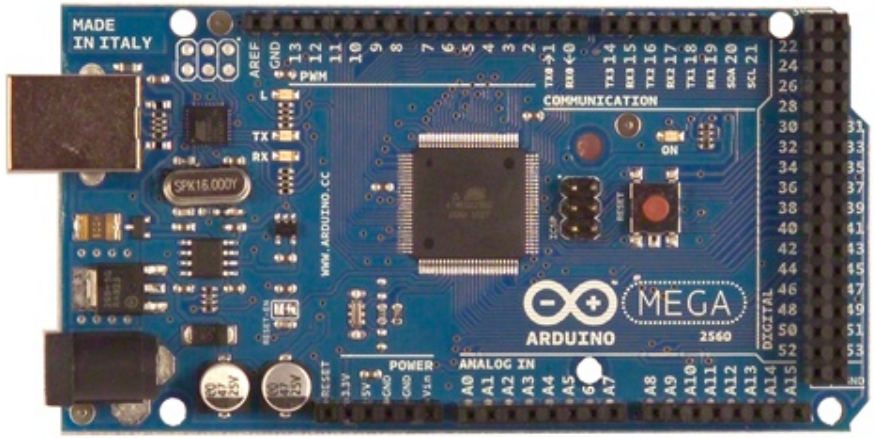
Boards



- Hardware issues with the beagleboard
- Changed to RaspberryPi

Boards(2)

- Arduino Atmega 2560
- Contains the flightsoftware
- With attached gyro, accelerometer, barometer, ultrasound rangesensor
- Wireless communication attached: GPS, Xbee wireless transmitter

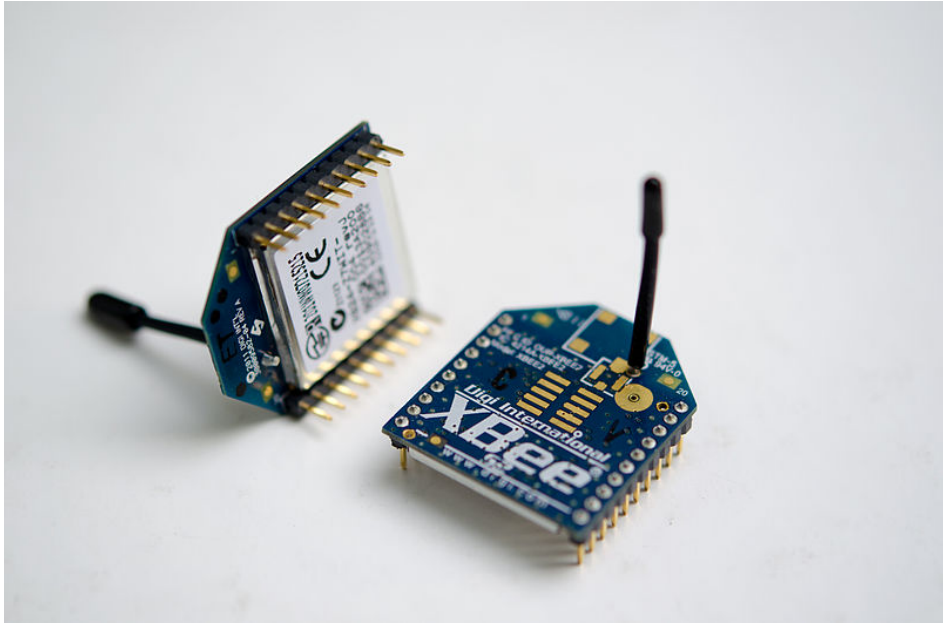


Remote control

- Digital remote control
- Graupner MX-16S
- 8 channel receiver attached to the Atmega board

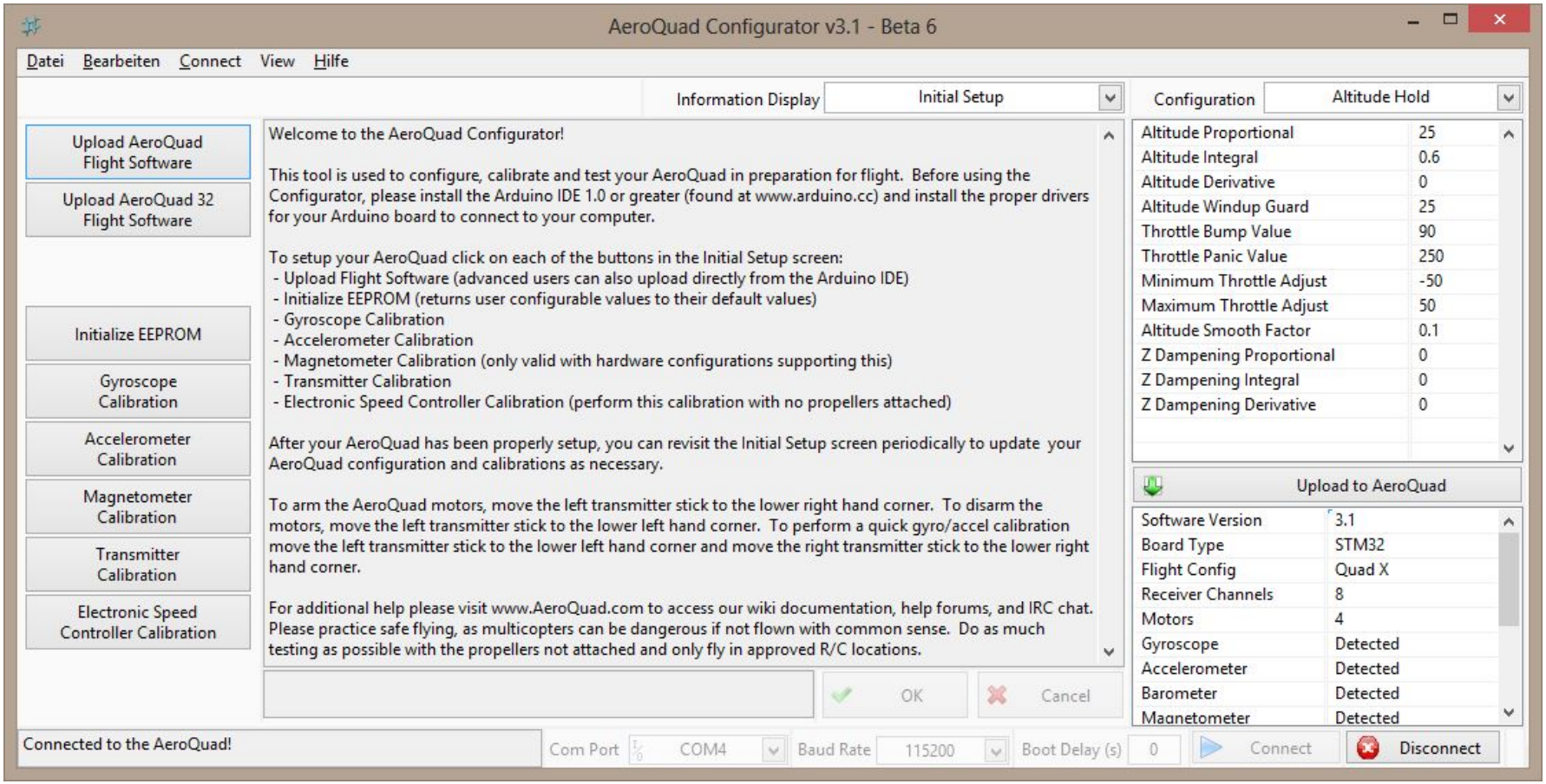
XBee wireless transmitter

- XBeePro S1
- Second XBee module used with USB dongle for wireless communication



Software, Calibration & Flying

AeroQuad Configurator



Flight Modes

1. Rate Mode

Uses only gyro data to stabilize

2. Attitude Mode

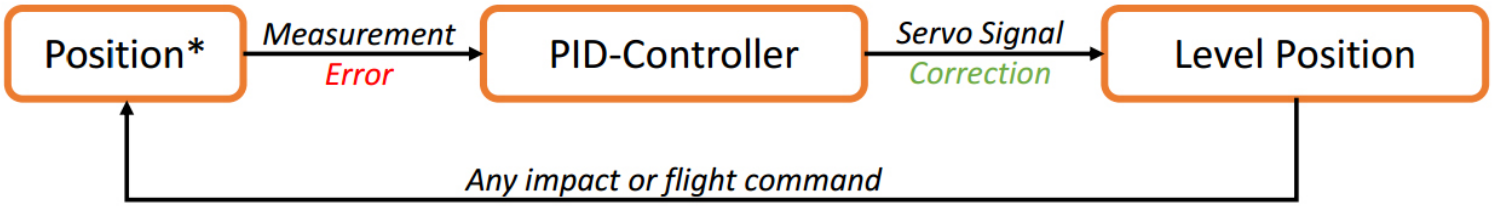
Uses gyro and accelerometer data to maintain level position
$\rightarrow$ "auto level" ability

3. Altitude Hold

Maintain the current distance to the ground using ultrasound and barometer

PID controller

- Proportional-Integral-Derivative controller is a generic control loop feedback mechanism
- Calculates error value as difference between measurement and desired setpoint
- Attempts to minimize that error



The Proportional

$$\boxed{y(t) = K_p \cdot e(t)}$$

$e(t) :=$ error

$K_p \;\; :=$ P-gain

$y(t) :=$ correction

- Most obvious control parameter
- Calculates error at time t
- Gain value controls sensitivity of correction

- Too big values: copter starts oscillating
- Too low values: copter reacts too slow

The Integral

$$\boxed{y(t) = K_I \cdot \int_0^t e(r)dr}$$

$e(t) :=$ error

$K_I \;\; :=$ I-gain

$y(t) :=$ correction

- 'Slowest' control parameter
- Utilizes errors of the past to prevent errors in the present
- Can eliminate the Steady-State-Error
- Is somehow buggy in the AeroQuad Software

The Differential

$$\boxed{y(t) = K_D \cdot \frac{d}{dt} e(t)}$$

$e(t) :=$ error

$K_D \;\; :=$ D-gain

$y(t) :=$ correction

- Guesses the error in the future

  $e'(t)$ assumes:

  If the error in $[t-1, t]$ is decreasing

  It will most likely decrease in $[t, t+1]$

- We did not really modify or experiment with the standard D-gain

PID controller

PID-Controller = P + I + D, or

$$\boxed{y(t) = K_p \cdot e(t) + K_I \cdot \int_0^t e(r)dr + K_D \cdot \frac{d}{dt}e(t)}$$

But how did we manage to find out the correct gain parameters?

PID controller

PID-Controller = P + I + D, or

$$\boxed{y(t) = K_p \cdot e(t) + K_I \cdot \int_0^t e(r)dr + K_D \cdot \frac{d}{dt}e(t)}$$

But how did we manage to find out the correct gain parameters?

We ~~guessed~~ calibrated them by in/decreasing over and over again

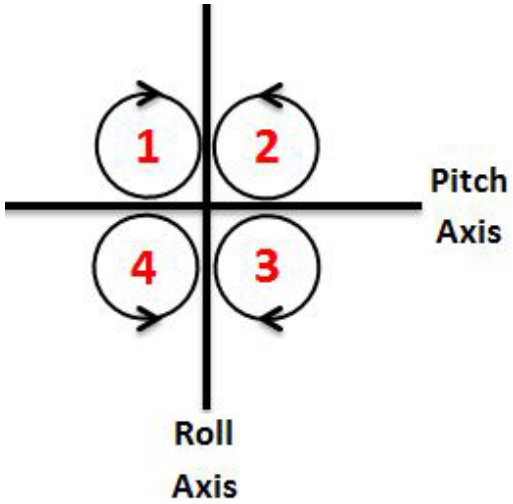
Problems

- AeroQuad configurator is really really bad
- PID-Calibration is not self-explanatory and not well documented
- Configurator produces random values
- Can fill random values in random forms (looks intended)
- Save and Recall PID-calibration file function broken
- Only working thing is the upload button

$\rightarrow$ New python software to up/download calibration

$\rightarrow$ Even more functionality e.g. parameters to tune altitude hold

Flying - Basics



Raise	Sink	Left(Yaw)	Right(Yaw)
↑ 1,2,3,4	↓ 1,2,3,4	↑ 2,4 ↓ 1,3	↑ 1,3 ↓ 2,4
Front(Pitch)	**Back (Pitch)**	**Left(Roll)**	**Right(Roll)**
↑ 3,4 ↓ 1,2	↑ 1,2 ↓ 3,4	↑ 1,4 ↓ 2,3	↑ 2,3 ↓ 1,4

Flying - Controls

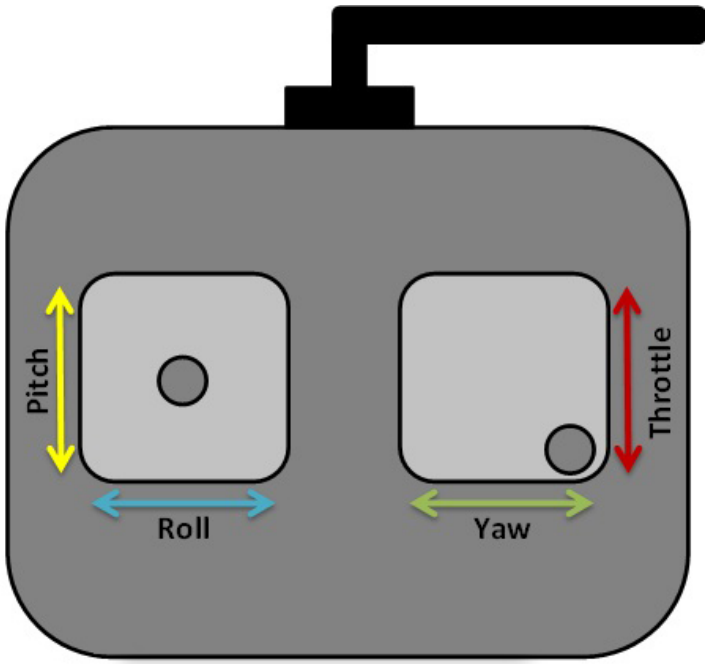
- Controlling all this by hand is impossible
- Reason that quadcopters became popular since 2000

  $\rightarrow$ High performance microcontrollers with gyroscope support make navigating possible

In addition:

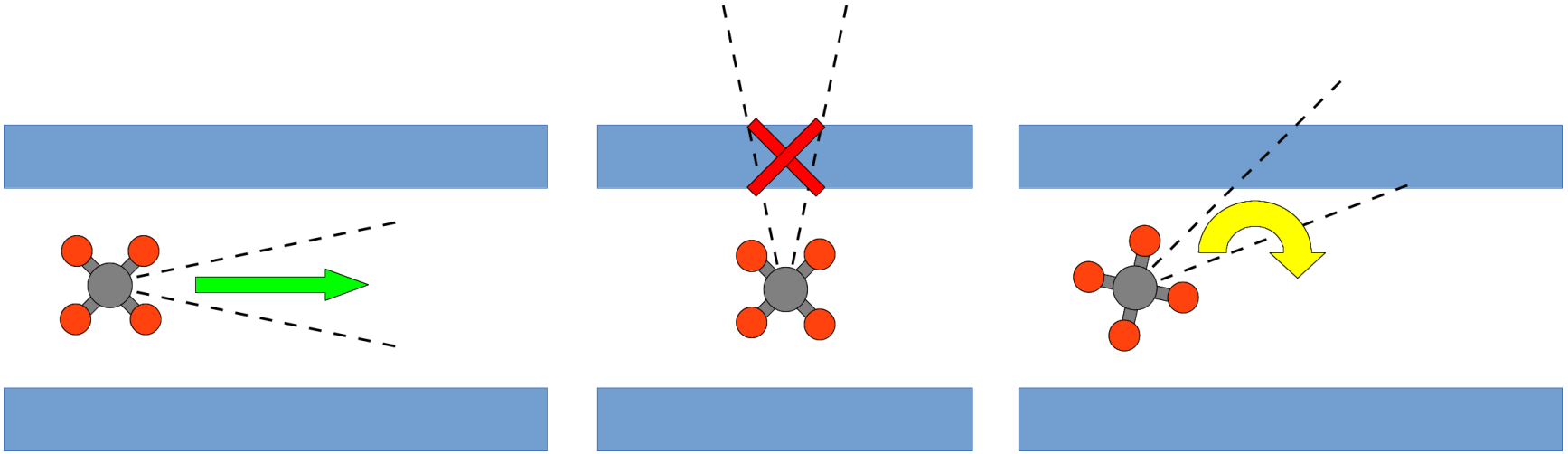
- Strong lithium polymer batterys
- Availability of small brushless motors

  $\rightarrow$ better power-to-weight ratio



Kinect data and object detection as further goal

Autonomous Obstacle Detection: Introduction



- Use sensor data (Kinect) to detect nearby obstacles (e.g. walls)
- Automatically avoid collision with them: stop or correct flight

Considerations

- Safety: It can be turned off at any time ($\Rightarrow$ manual control)
- Performance: The software has very limited time to decide
- Extensibility: Other programs might want to use the sensor data, too

Autonomous Obstacle Detection: Approach

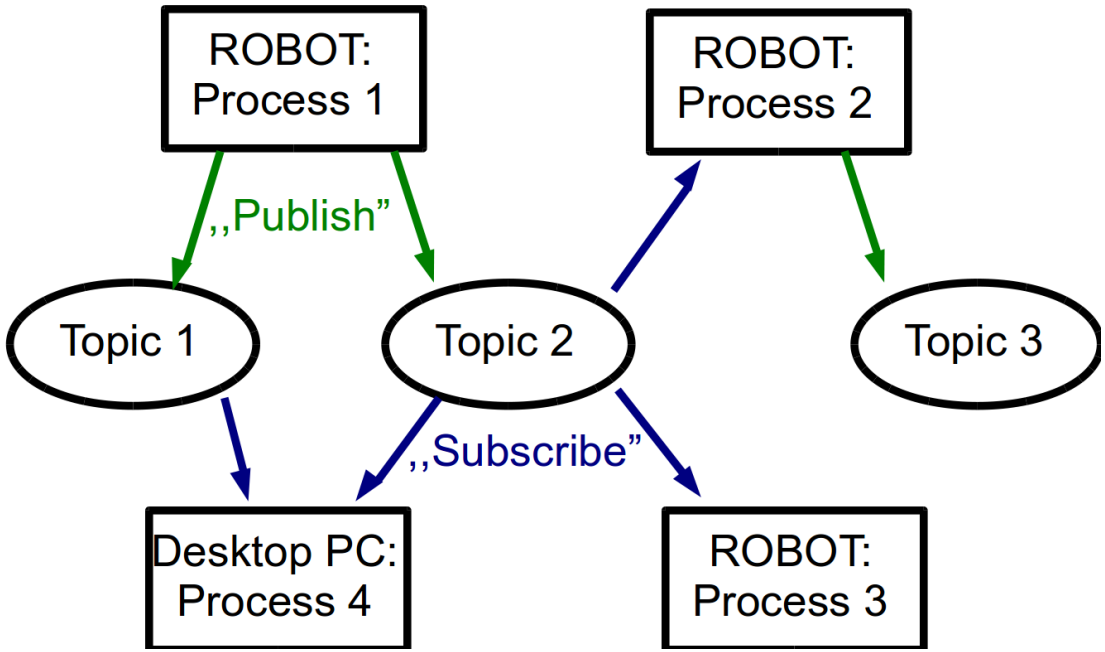
- Start with a simple, efficient prototype 1 (forward or stop)
- When things go well, implement more accurate algorithm 2
  $\Rightarrow$ e.g. for corrections, planning ahead, temporal reasoning, ...

Benefits of this approach

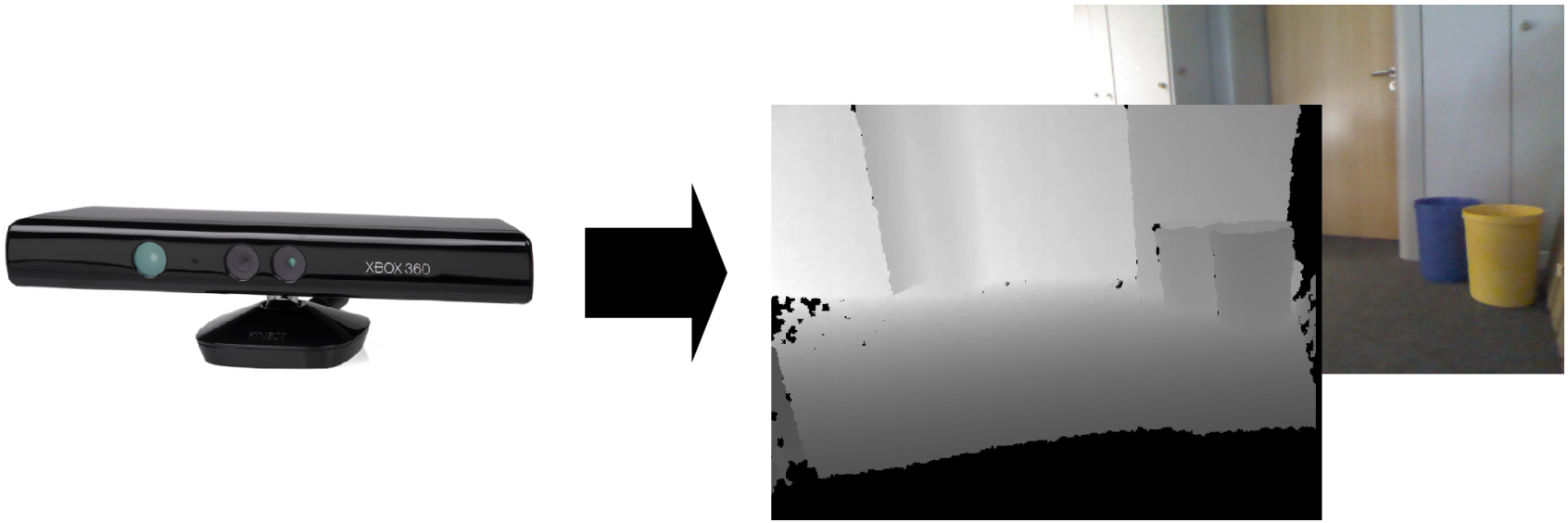
- 1 as emergency stop without unexpected effects/bugs
- Sanity check for reference (to debug 2)
- Gaining knowledge, to find out which algorithm 2 will work out:
  - How far can we go? (Performance evaluation)
  - How does the input look like (size, distribution, extrema)?
  - Which (optimised) functions/algorithms are already supported?

Framework of choice: ROS

- **R**obot **O**perating **S**ystem
- Various features, e.g. 3D visualisation of sensor data
- "Topics": message passing between processes (1 in, 0..N out)



Kinect

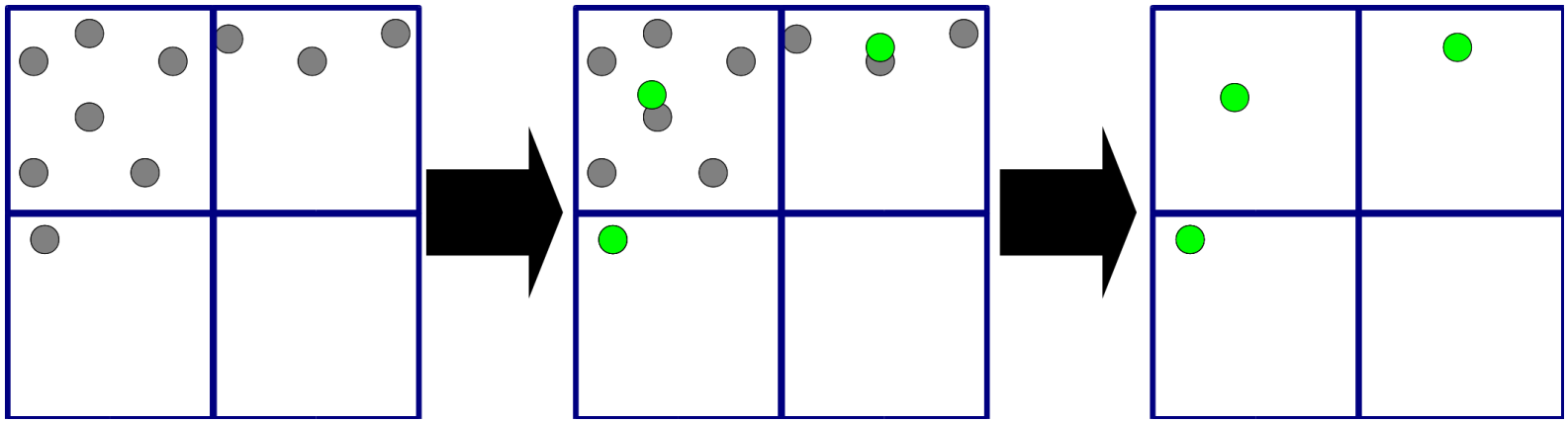


Microsoft Kinect

- RGB camera (640x480, 30 Hz)
- Depth camera (for "Clouds" of 3D-points)
- Accessable by ROS using OpenNI (Open source SDK)
- ROS has a **P**oint **C**loud **L**ibrary

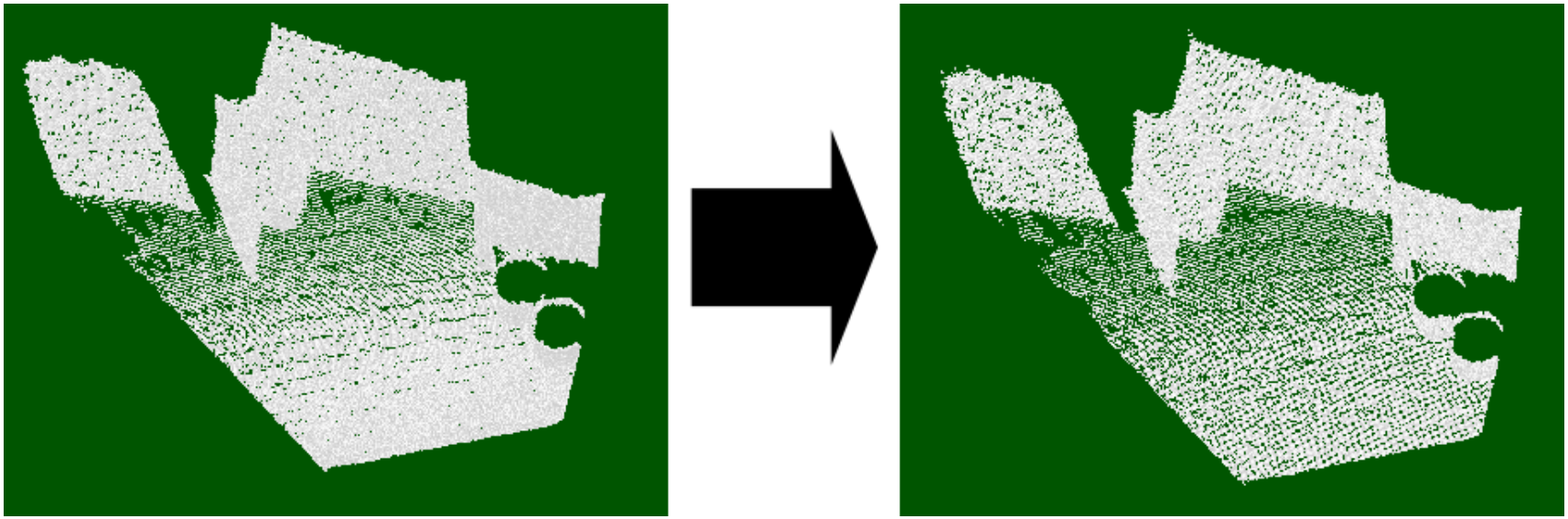
Pointclouds and Downsampling

- Issue: analysing many points = bad performance



- Solution: combine similar points into one
- Downsampling (PCL): use centroids (= means) of Voxel grid cells

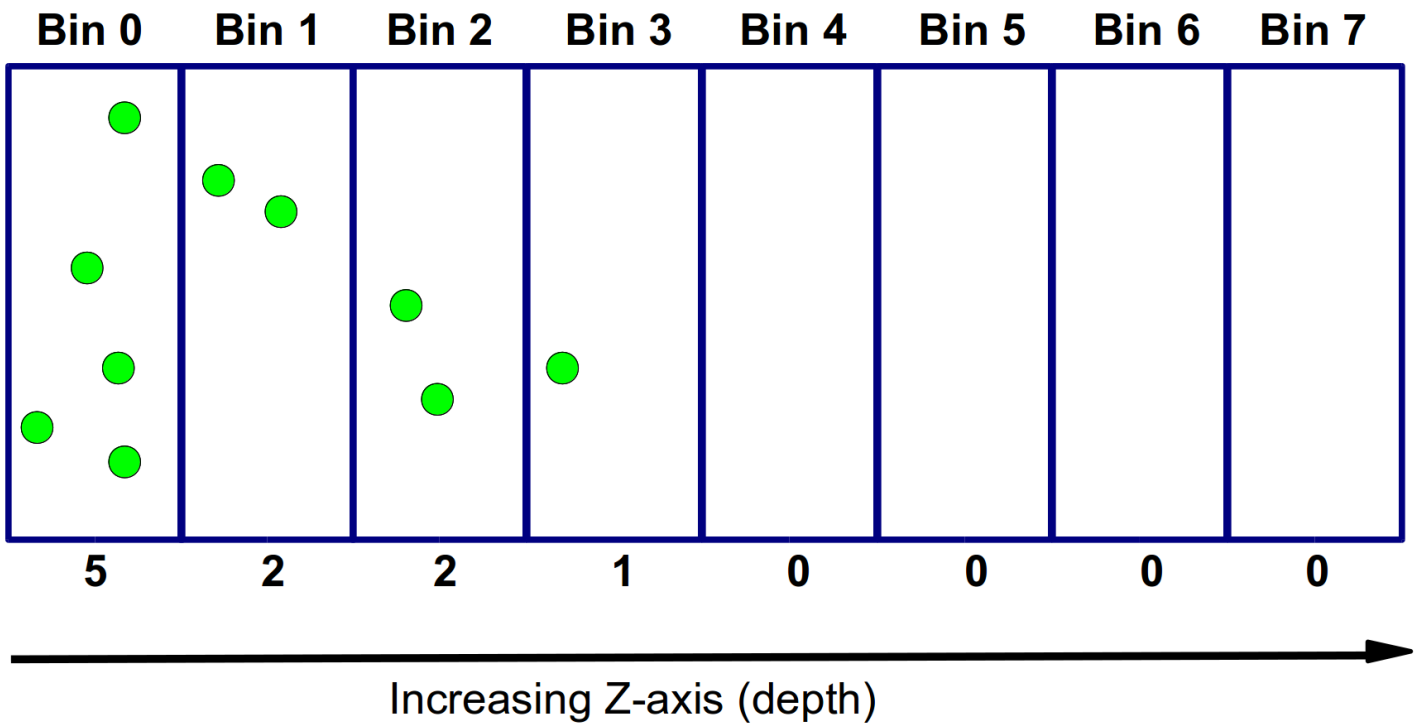
Downsampling: Example



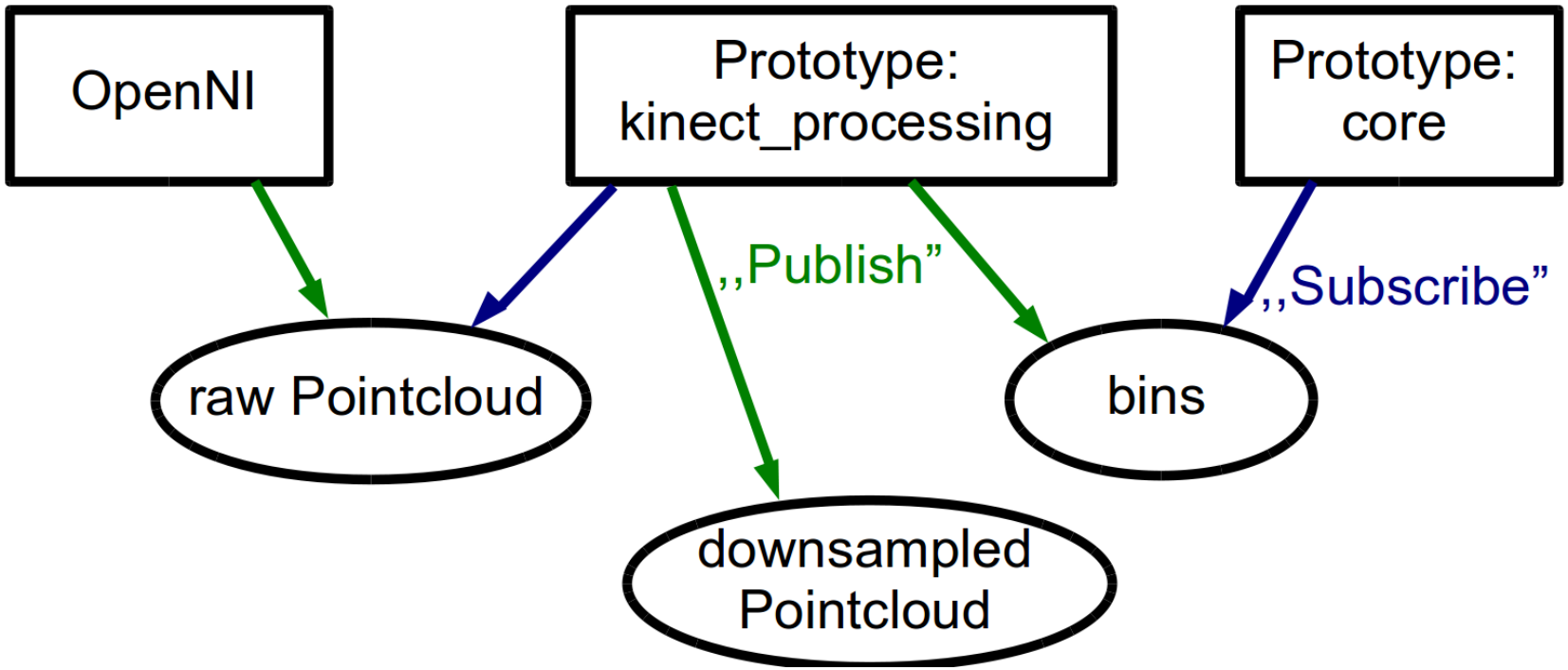
- Shapes remain intact
- Here: ca. 250.000 points reduced to ca. 74.000 points
- About 70% of the original points have been discarded

Our Prototype

- Applies Downsampling
- Accumulates points with similar depth into the same "bins"
- Computes extrema for all dimensions (feel for data)
- Avoids floating-point operations: slow on RaspberryPi



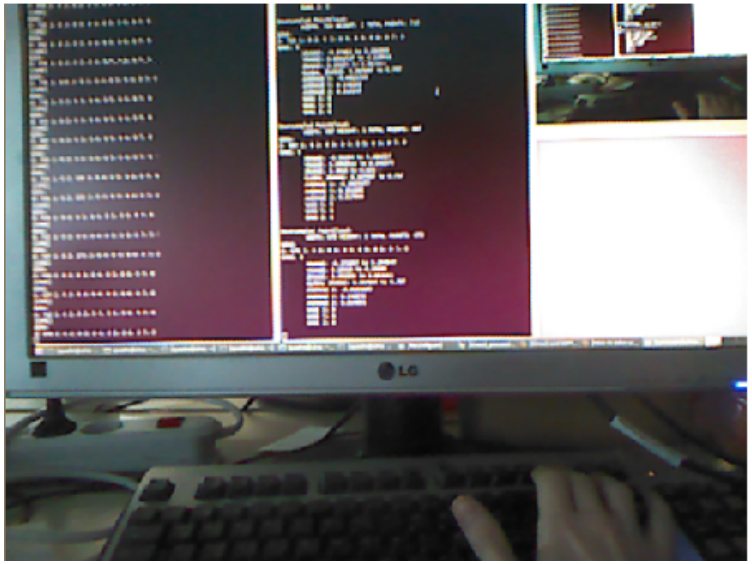
Our Prototype: Architecture

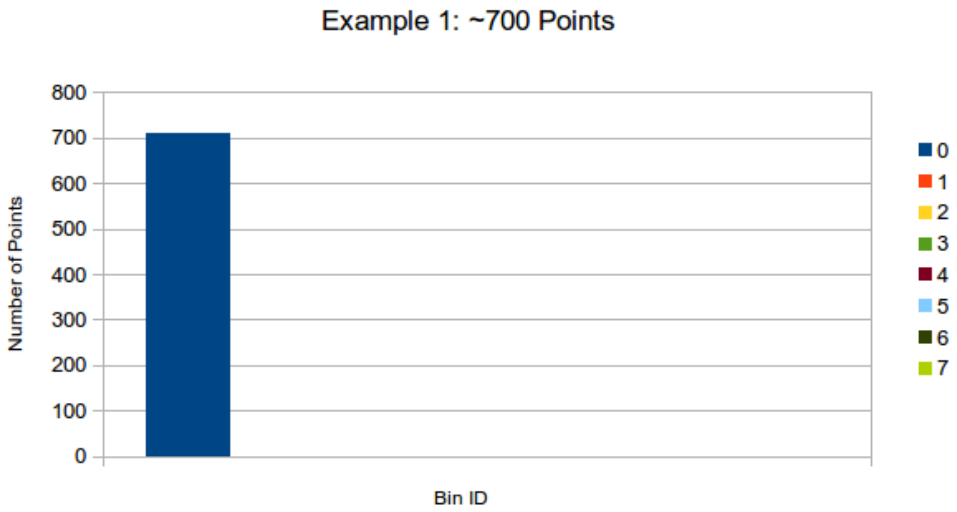


Core:

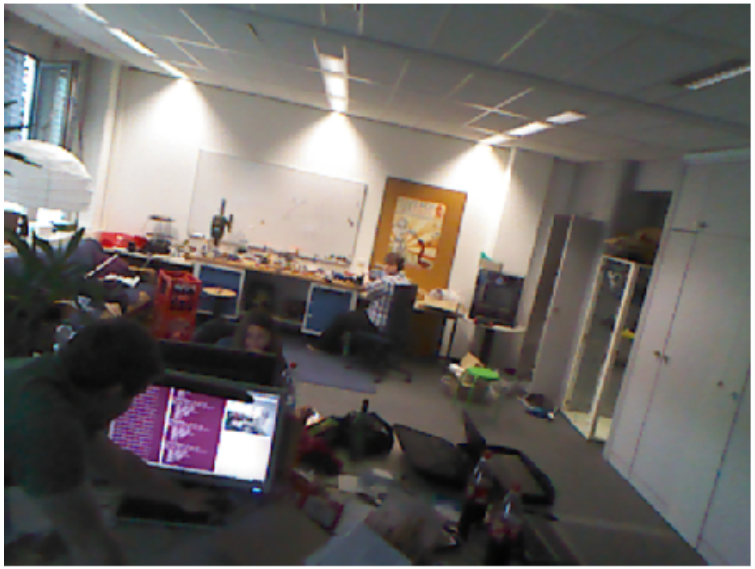
- responsible for steering decisions
- can iterate much faster than kinect_processing
- could incorporate other sensor data and algorithm results

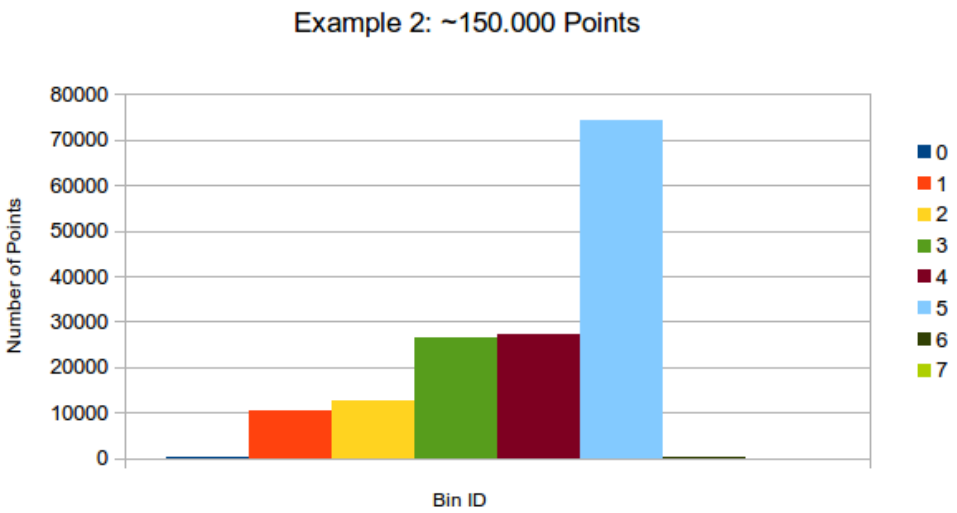
Our Prototype: Practical examples (1/5)



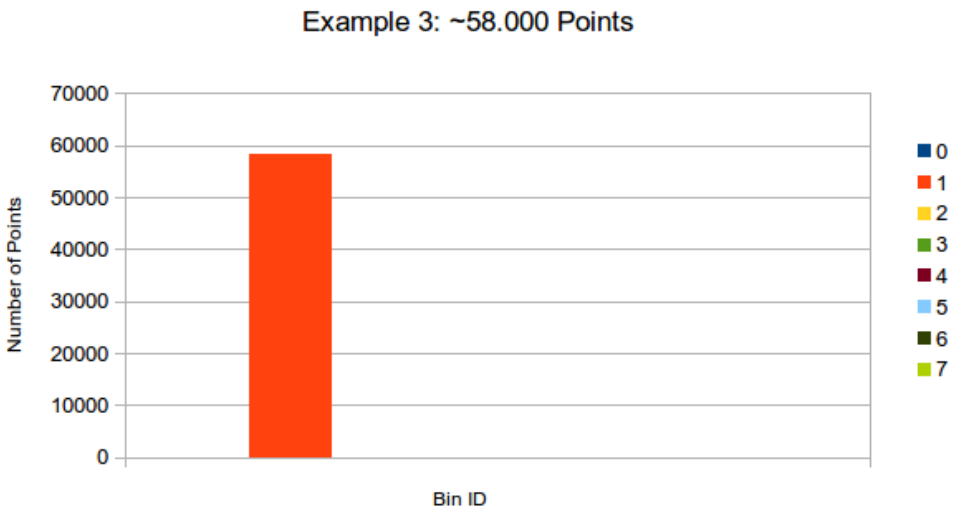


Our Prototype: Practical examples (2/5)



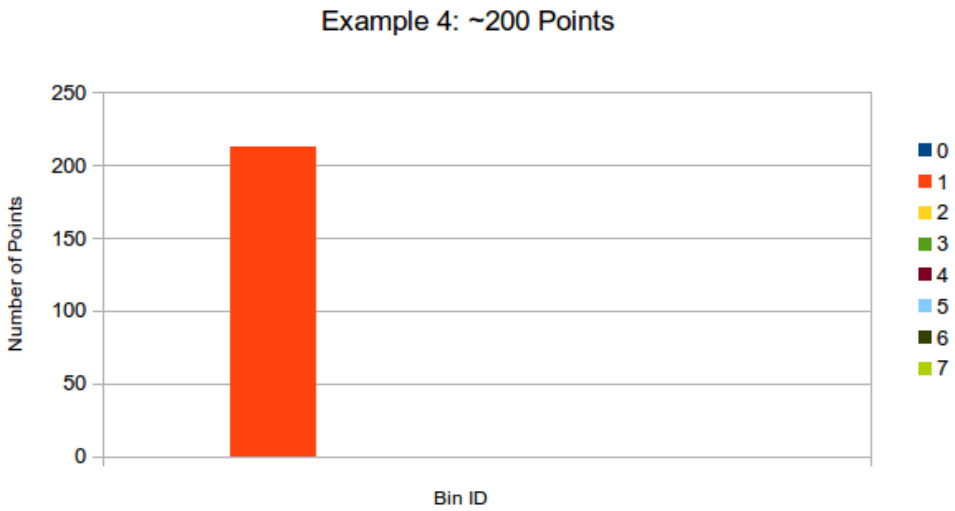


Our Prototype: Practical examples (3/5)



- "Camera-beams" are radial: dense points on objects which are closer
- No matter how dense a grid-cell is: only 1 centroid
- Close objects $\Rightarrow$ fewer points

Our Prototype: Practical examples (4/5)



Our Prototype: Practical examples (5/5)

- Zero points in the Pointcloud
- $\Rightarrow$ there is a minimum distance

Our Prototype: Findings

- Few points indicate close objects
  - "Holes" due to minimal distance
  - Close objects $\rightarrow$ dense points $\rightarrow$ few centroids
- Downsampling helps a lot, but takes ca. 50ms (Desktop PC!)
- Bounding Box (global extrema over recording time):
  - x, y : roughly -5 to $+5$ each
  - z : 0.3915 to 9.75 ($\Rightarrow$ used binsize: $\frac{10}{8} = 0.125$)

Our Prototype: Problems

- Many NaN-values for Point-coordinates
  - Filtered out by downsampling
  - Manual filtering: $(v! = v)$
- Unstable indoor flight (until recently)
- OpenNI not working with ROS on RaspberryPi!

$\Rightarrow$ stopped further development and put more focus on hardware

Outlook

- Optimize Downsampling for RaspberryPi
  - Avoid floating point operations
  - Think of other methods
- Try out other sensors/software
- If things work out: implement more advanced algorithms
- Improve hardware even further

Thank You!