Autonomous guidance for a UAS along a staircase using visual servoing

2VZ KBO DE MEYST
OLt KBO GOETHALS

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165th Promotion Polytechnics
Lt-Col avi Vaerten


JE SUIS CHARLIE
3
HYPER CACHER
SOIR/3 L'INTERVENTION DU RAID PORTE DE VINCENNES

Context

- Indoor reconnaissance
- Obstacle avoidance

Objectives

- Staircase detection
- Autonomous guidance

Parrot AR.Drone 2.0

- Cheap and directly available
- Sensors low quality
- Off-board processing

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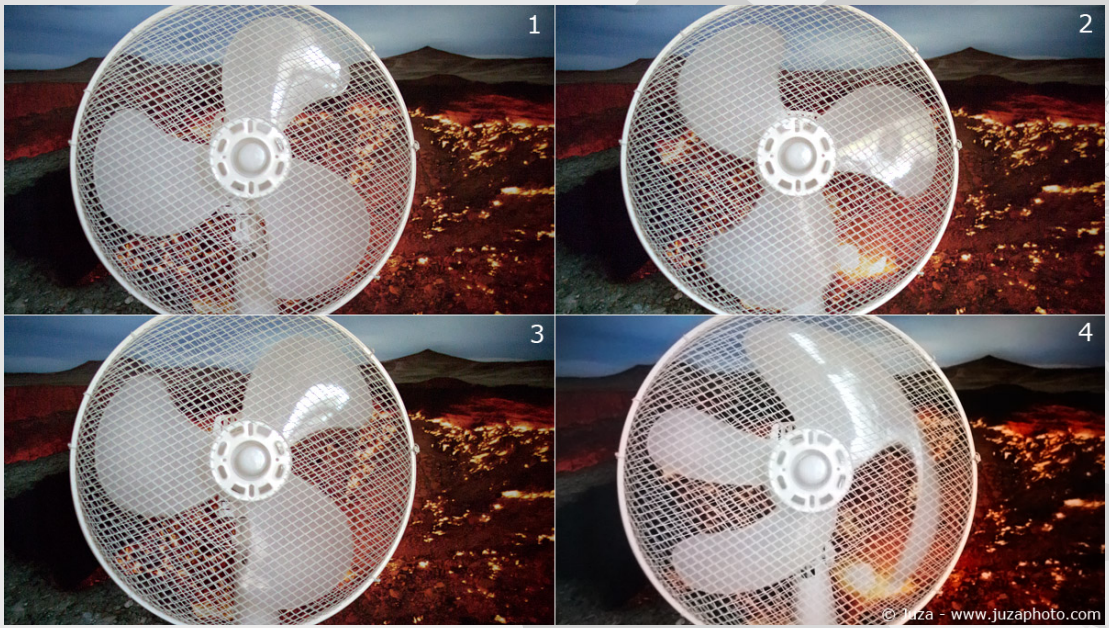


ROS

- Robot Operating System
- C++ and Python
- Large community


```
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://pegasus:41219/
ros_comm version 1.11.13


SUMMARY
========

PARAMETERS
 * /rosdistro: indigo
 * /rosversion: 1.11.13

NODES

auto-starting new master
process[master]: started with pid [20536]
ROS_MASTER_URI=http://pegasus:11311/

setting /run_id to 32987992-0e7f-11e5-8b4b-0026b9edcce3
process[rosout-1]: started with pid [20549]
started core service [/rosout]
```

Positioning

Understand Environment

Control

Software package Extended Kalman Filter

Positioning

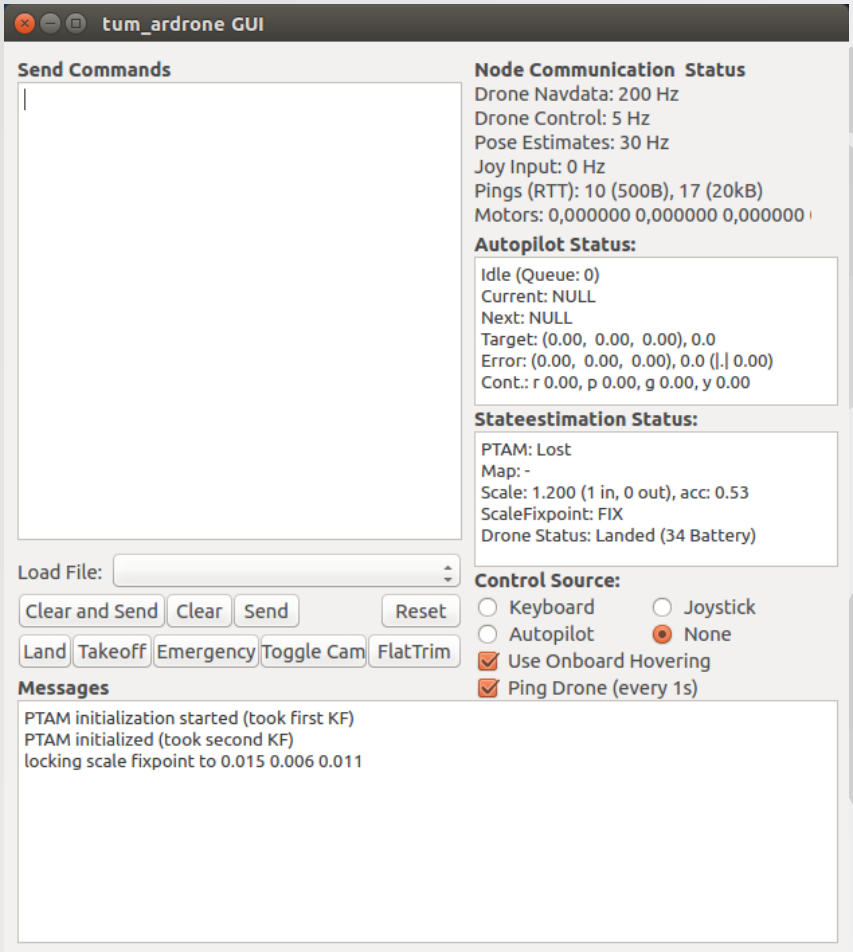
- TUM AR.Drone
- EKF

Understand Environment

Control

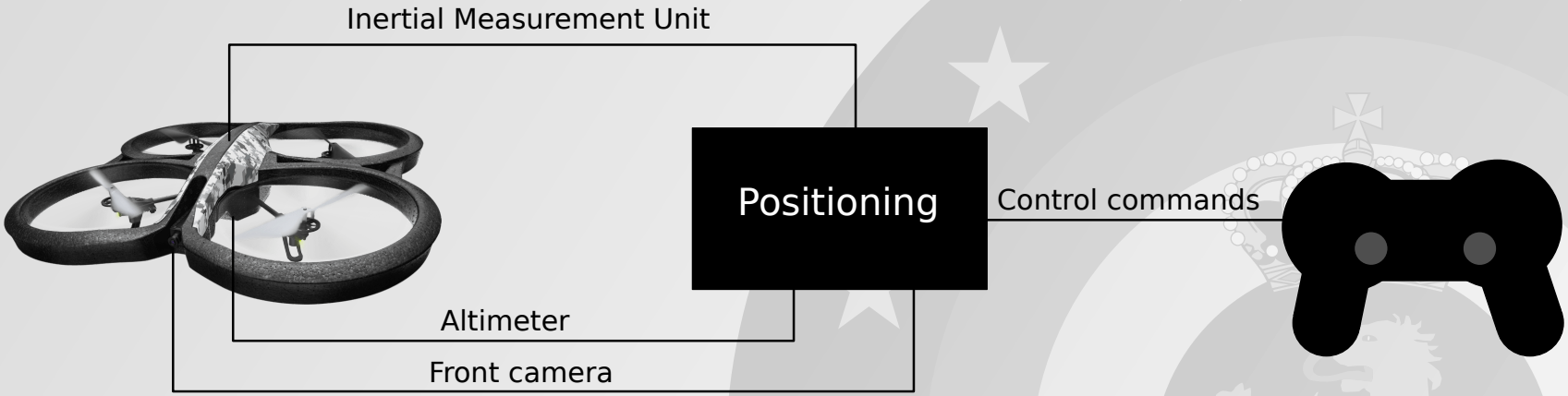
Software package Extended Kalman Filter

TUM AR.Drone

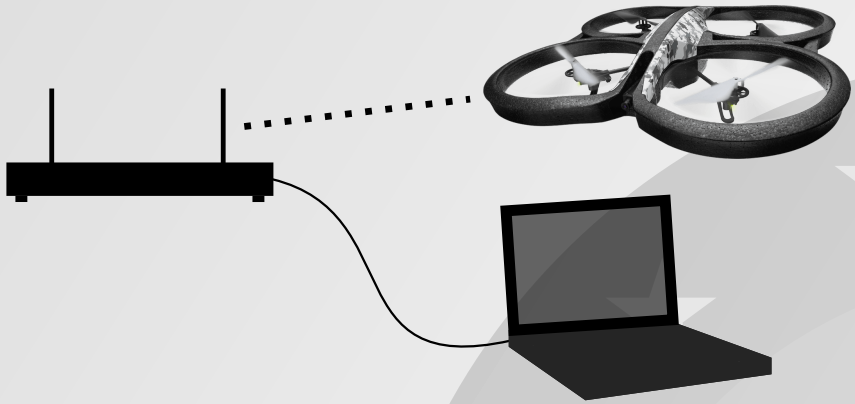



Rege duce pro Jure et Honore

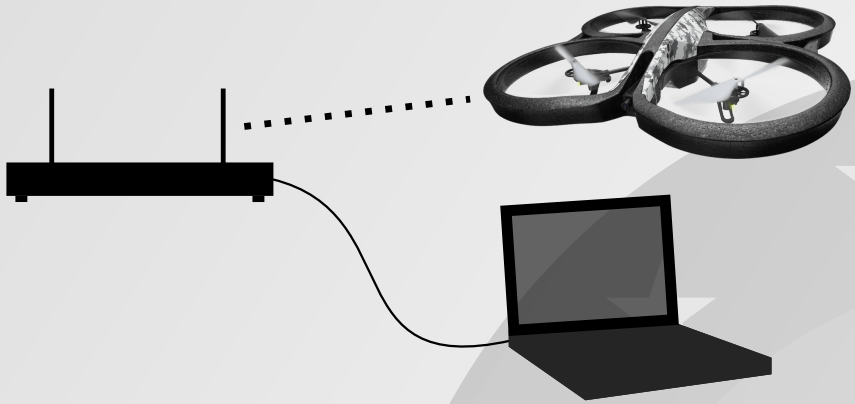
Structure


Inertial Measurement Unit
Positioning
Control commands
Altimeter
Front camera

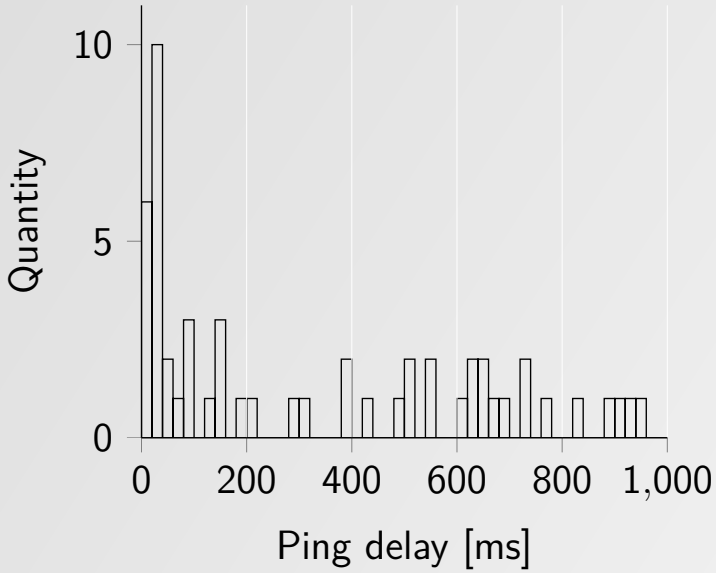
Delay determination



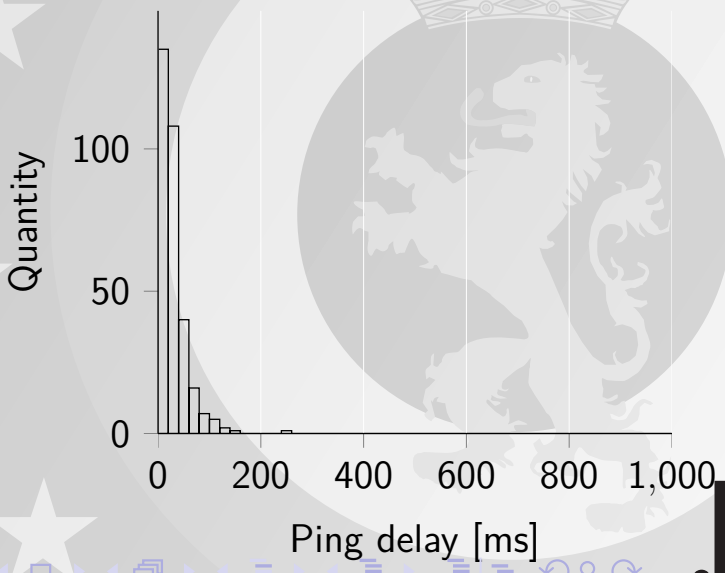
Delay determination



Static ping delay without AP (20 kB)

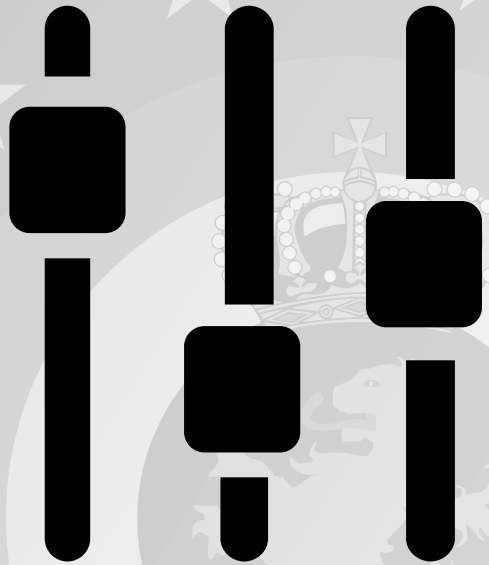


Static ping delay with AP (20 kB)



Modifications

- Changed hardcoded IP address
- Added ROS position broadcaster



Positioning

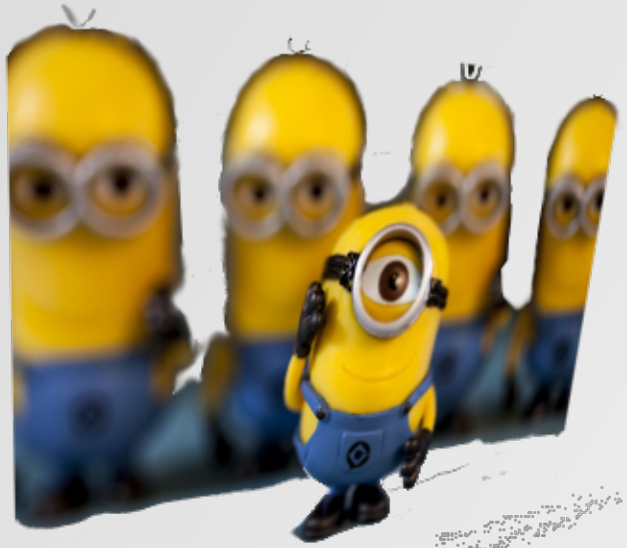
- TUM AR.Drone
- EKF

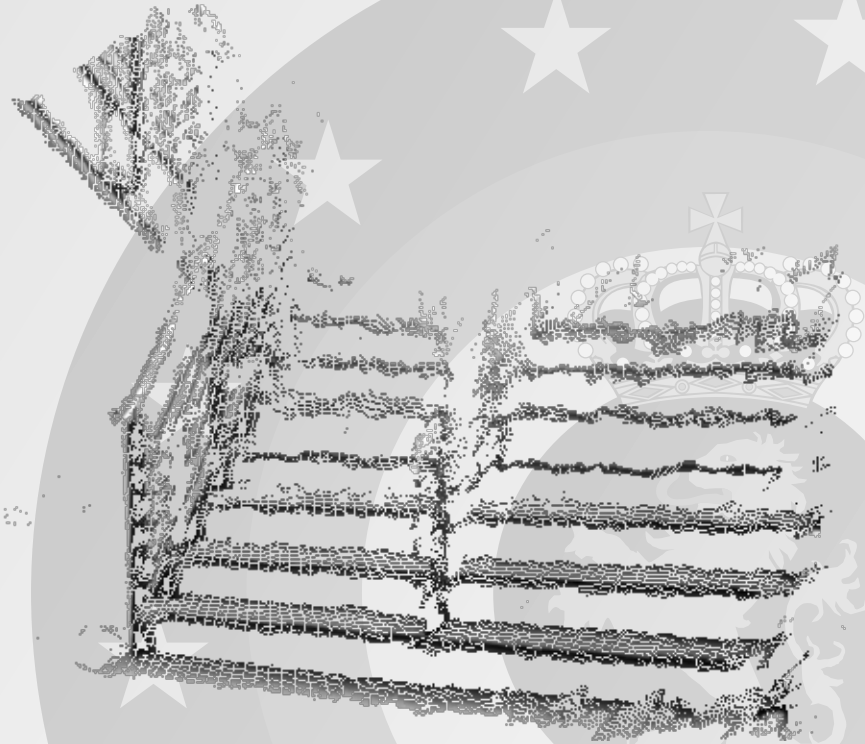
Control

Understand Environment

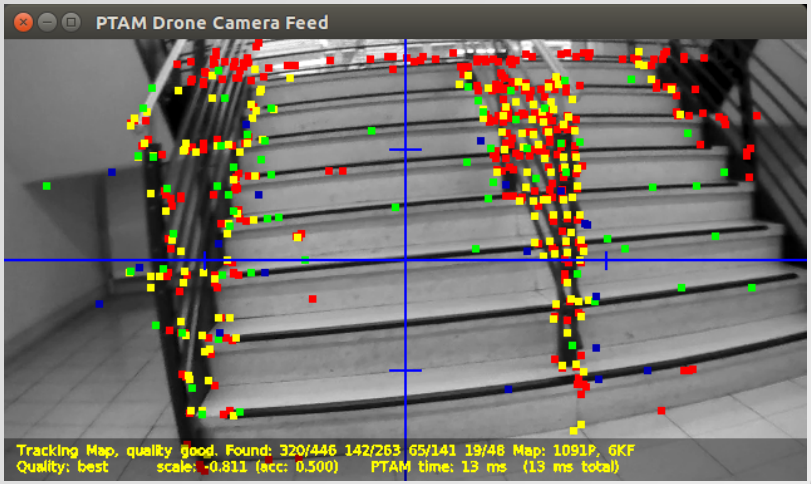
- SLAM
- Detection

Monocular SLAM



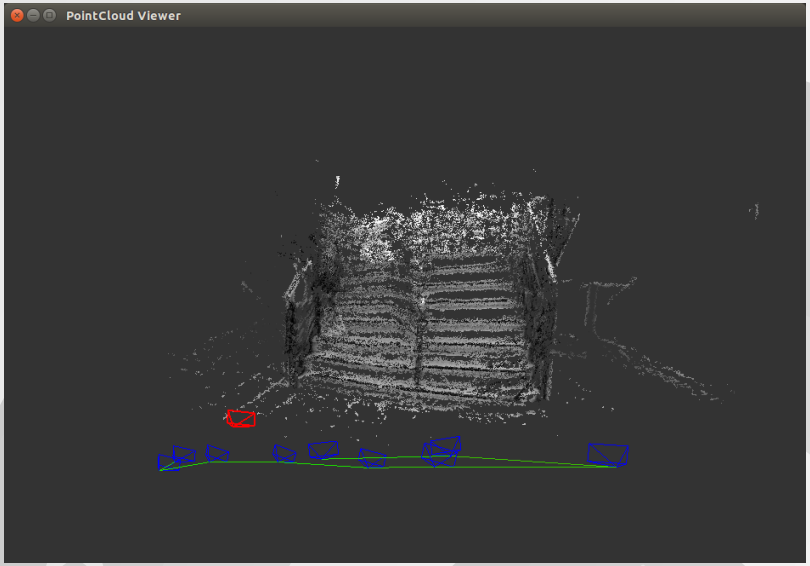


Methods



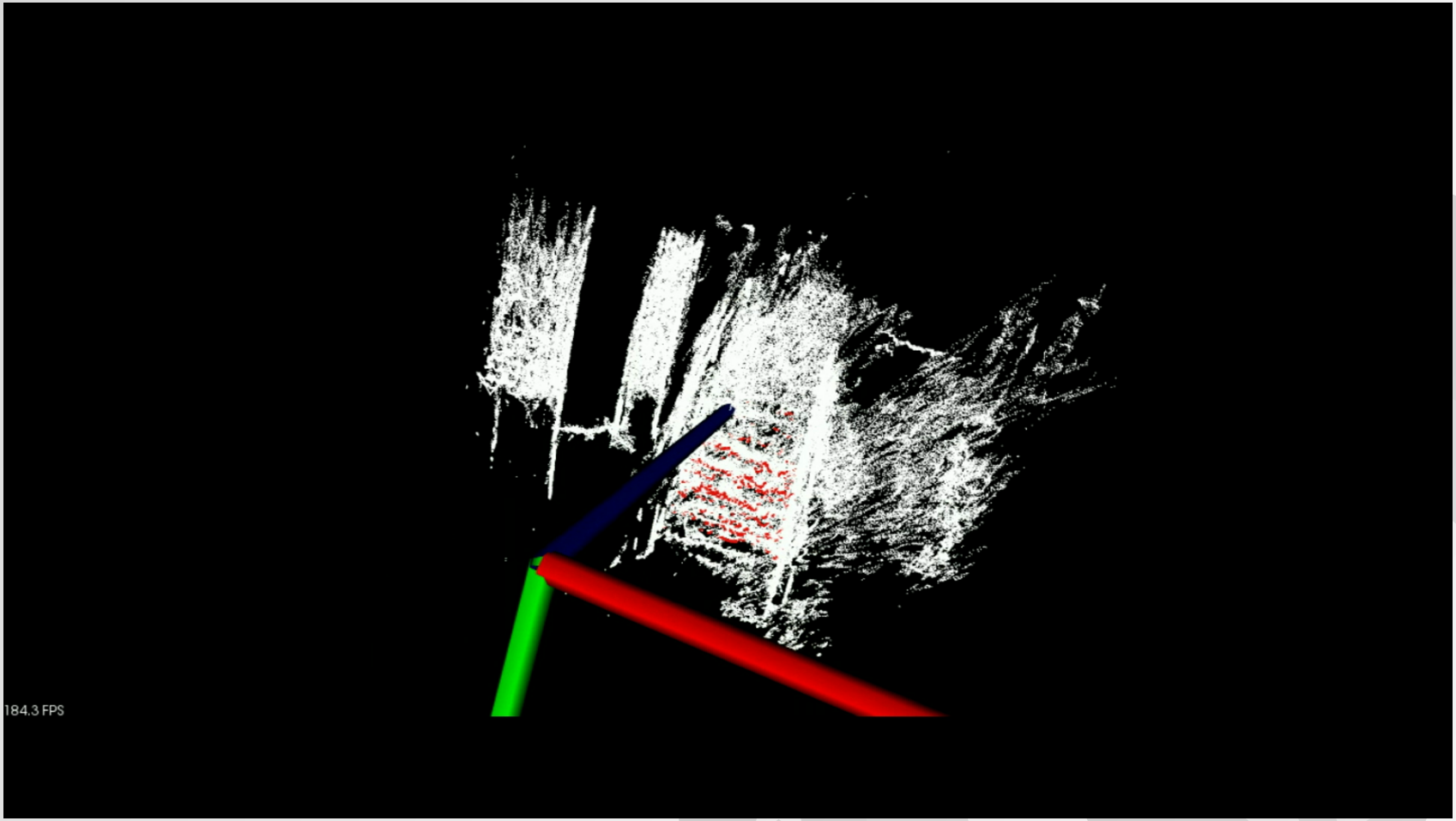
Feature-based methods

- Very robust for large camera movements
- PTAM, ORB-SLAM, ...

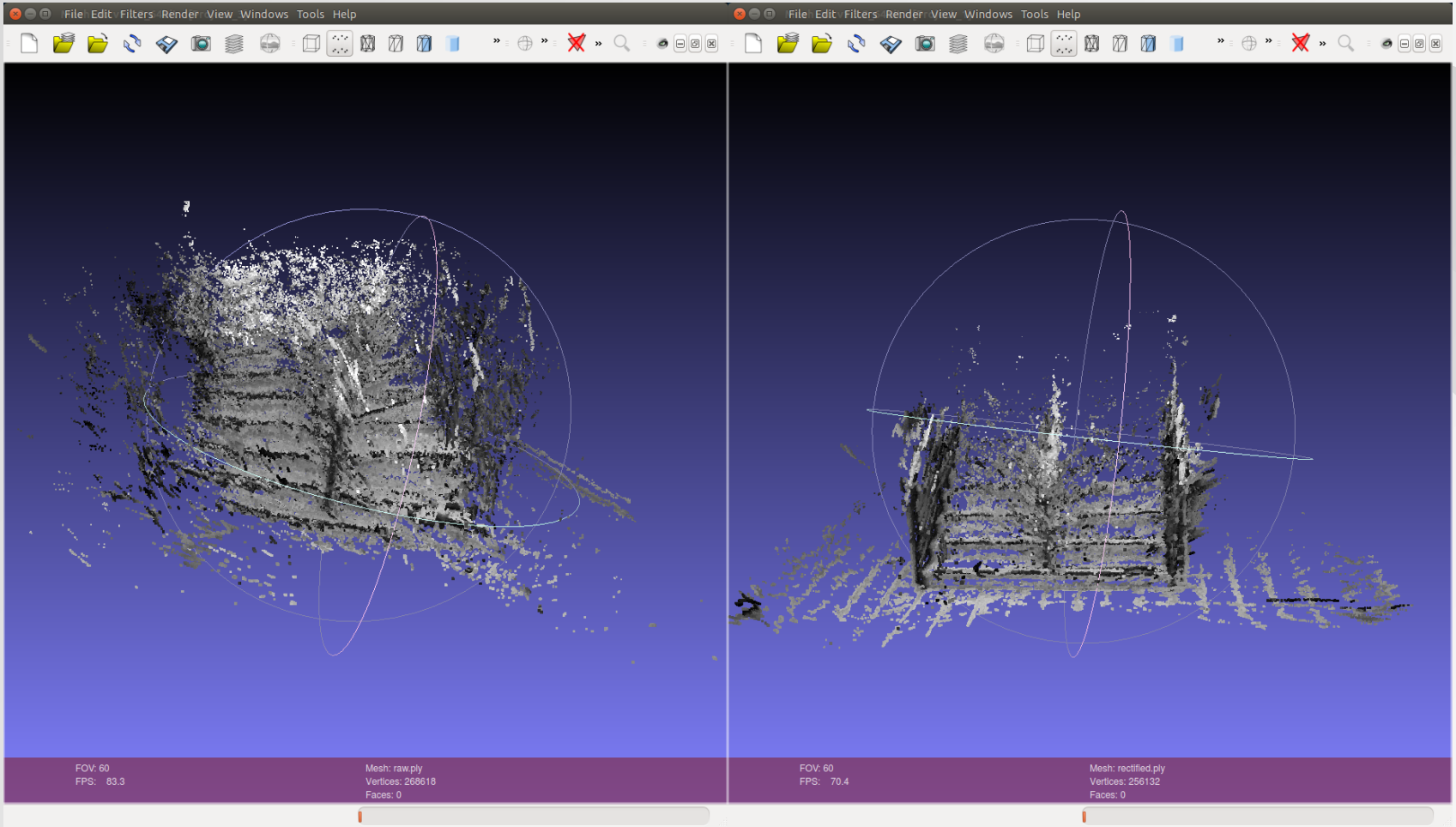


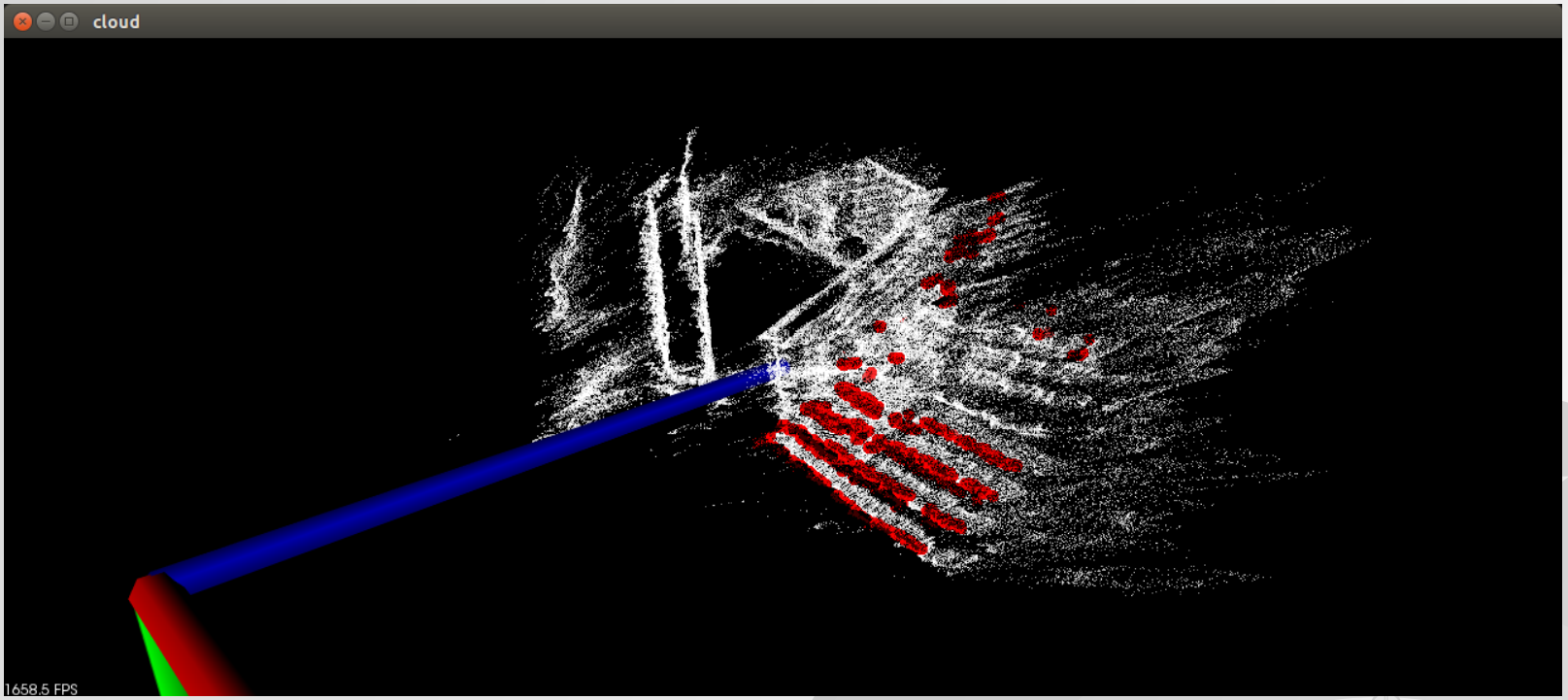
Direct methods

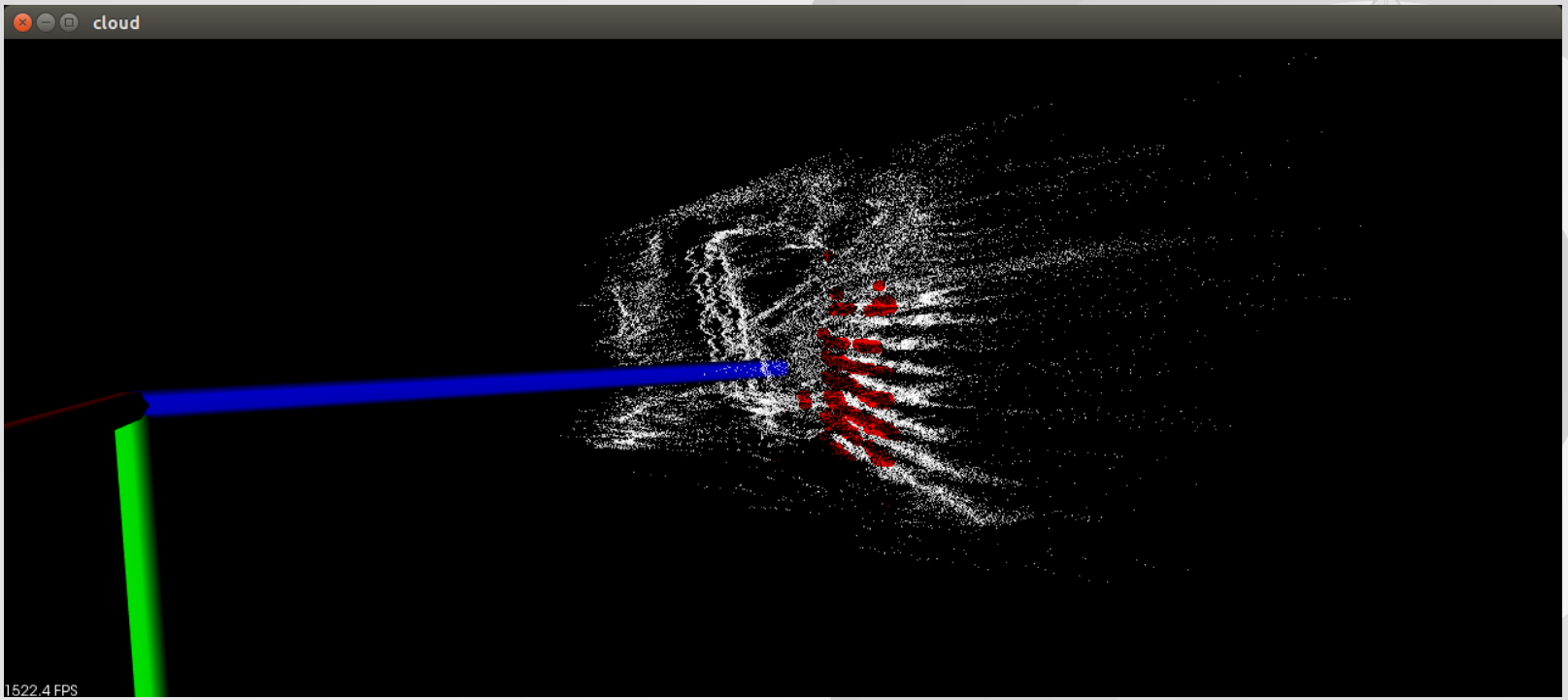
- Better to create a dense depth image
- DTAM, LSD-SLAM, ...


184.3 FPS

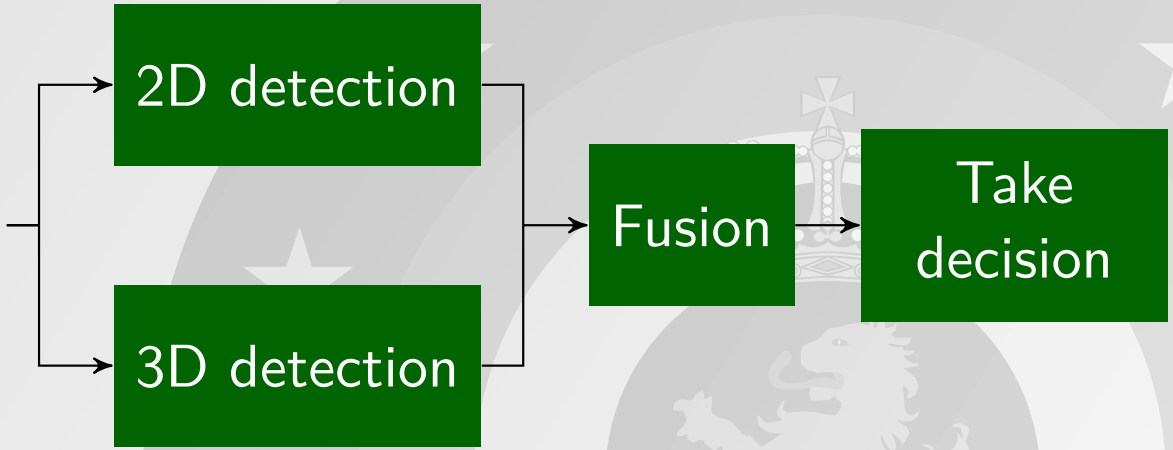
Influence rectification




cloud
1658.5 FPS


cloud
1522.4 FPS

Overview detection



2D detection

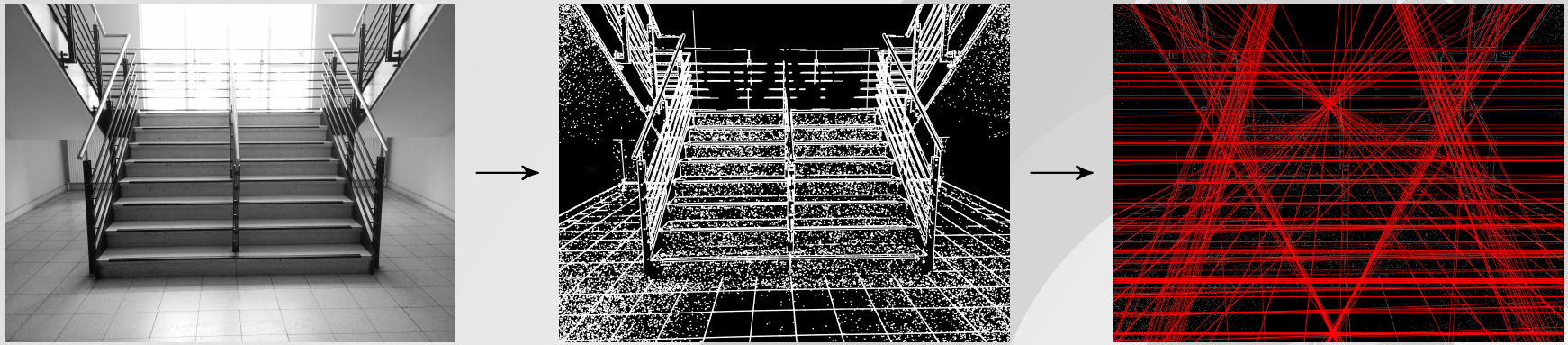
- line detection
- object detection
- line clipping

3D detection

Fusion

Take decision

Line detection: classic approach

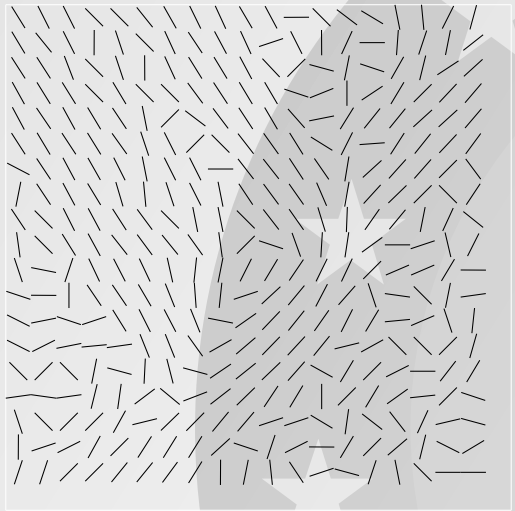


- parameter tuning
- hough transform computational intensive

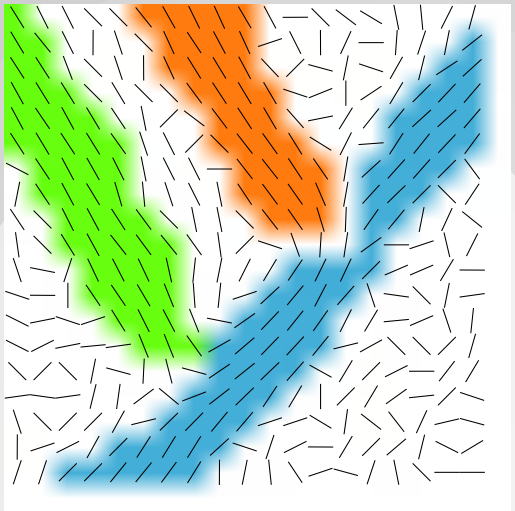
Line Segment Detector

- Gradient based
- Unitary level lines
- Level-line angle

Image

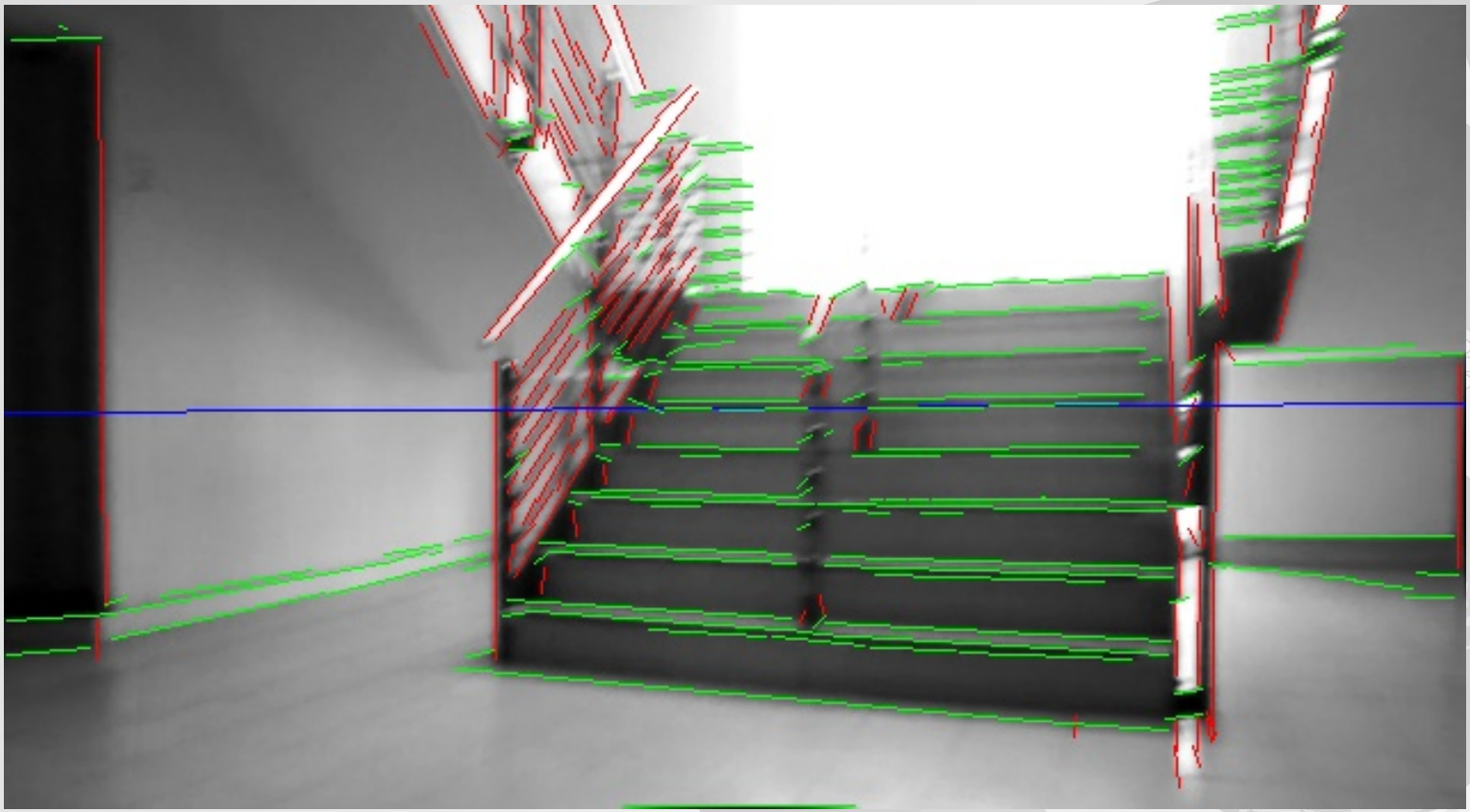


Level-line field

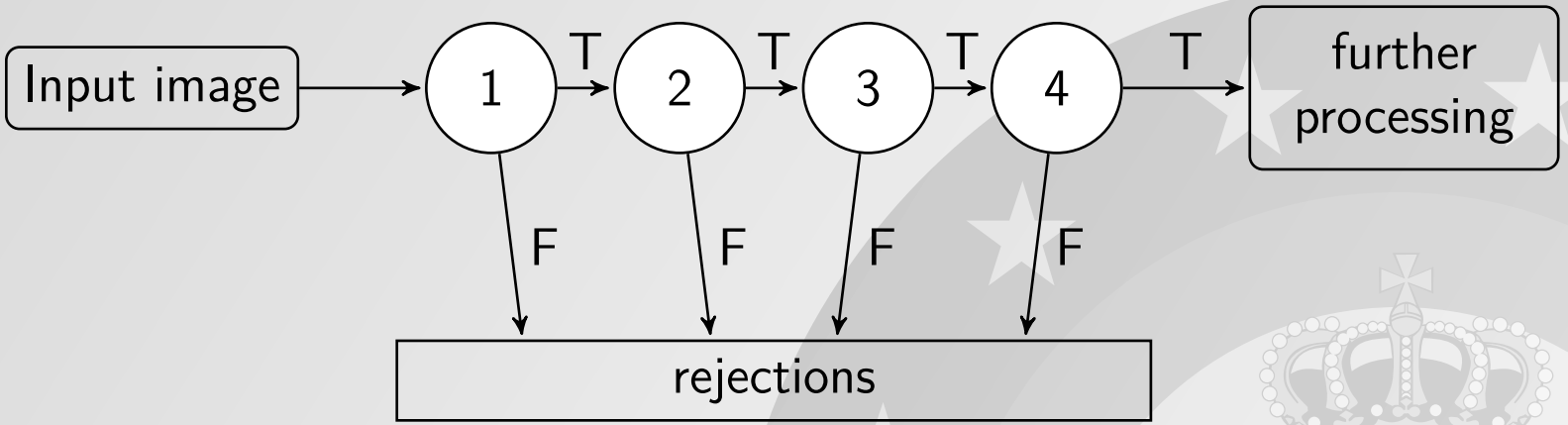


Line support regions

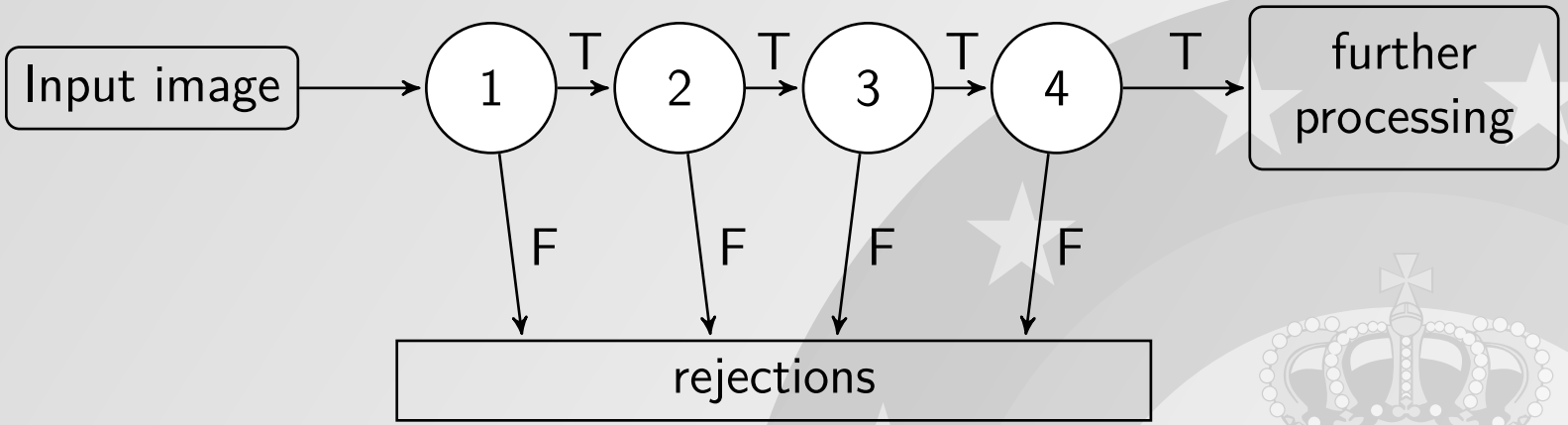
Horizontal lines



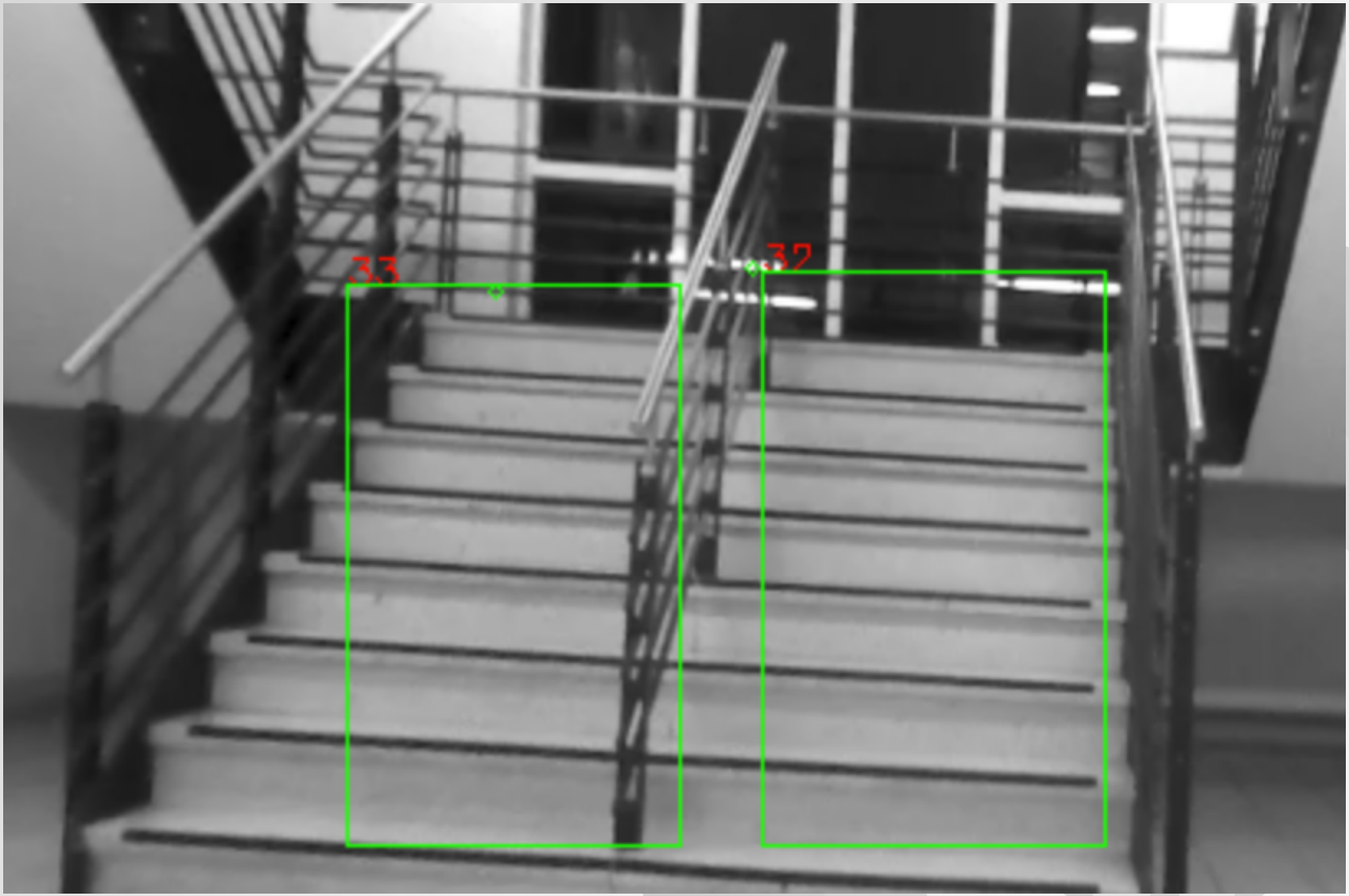
Object detection



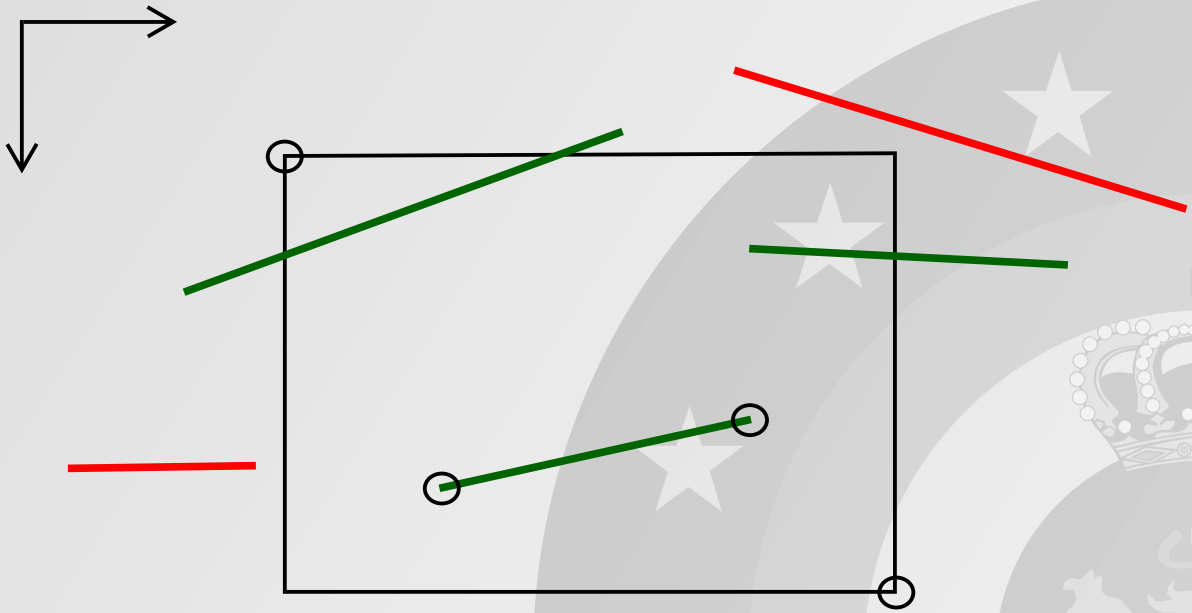
Object detection



- intensive training
- Known and tested algorithm

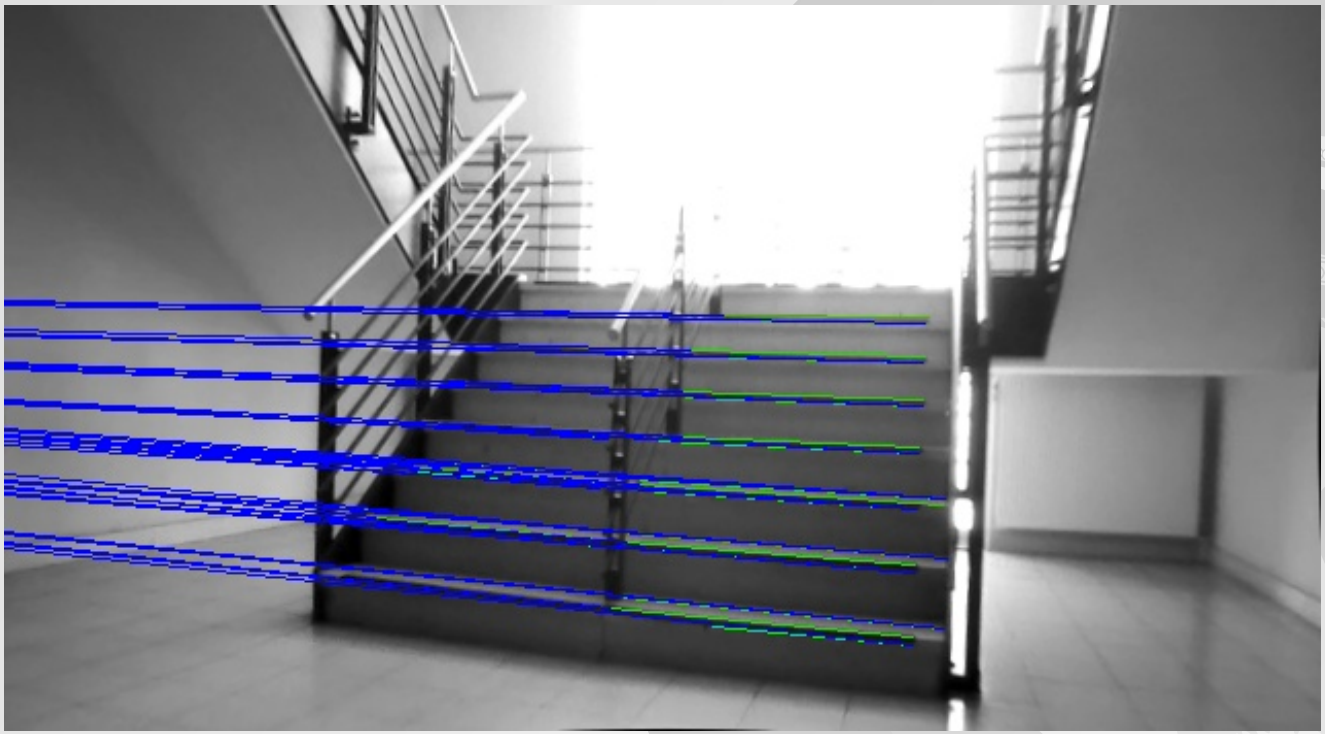

33
32

Line Clipping: Cohen Sutherland



Robust fitting

- Quasi-parallel (< 0.02 rad) lines: mean slope
- Non-parallel lines: vanishing point



2D detection

- line detection
- object detection
- line clipping

3D detection

- depth image

Fusion

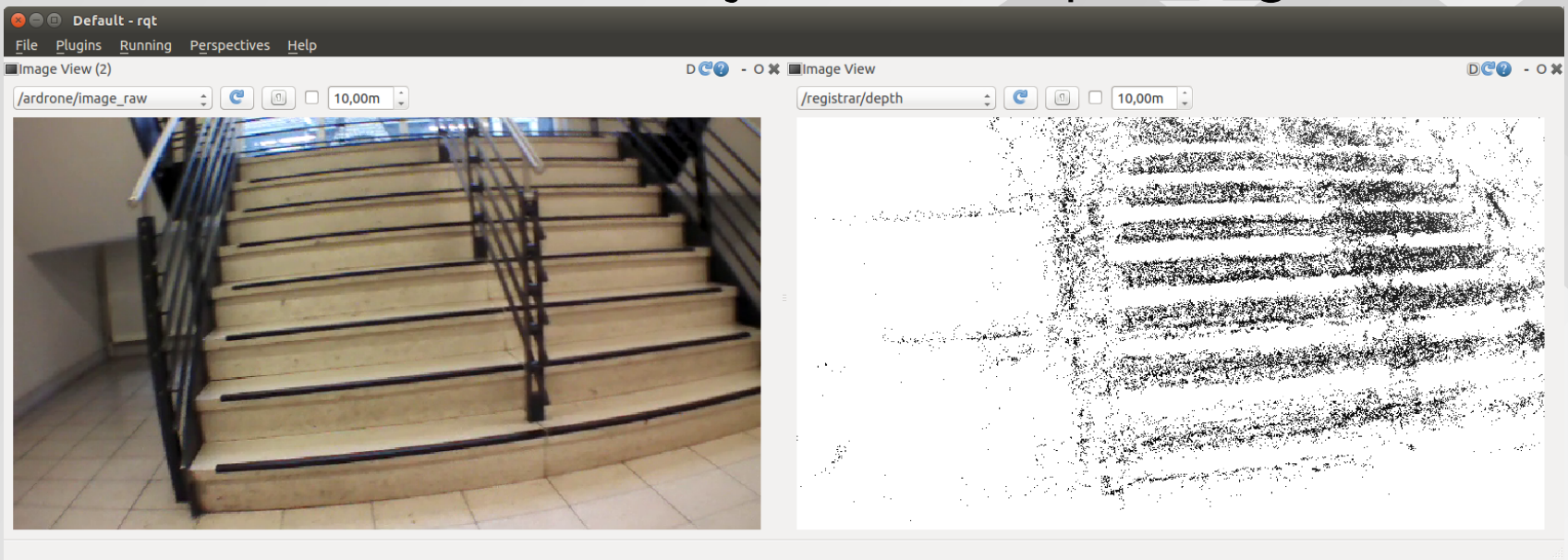
Take decision

3D depth image

LSD-SLAM → Projection → Depth image

3D depth image

LSD-SLAM → Projection → Depth image



2D detection

- line detection
- object detection
- line clipping

3D detection

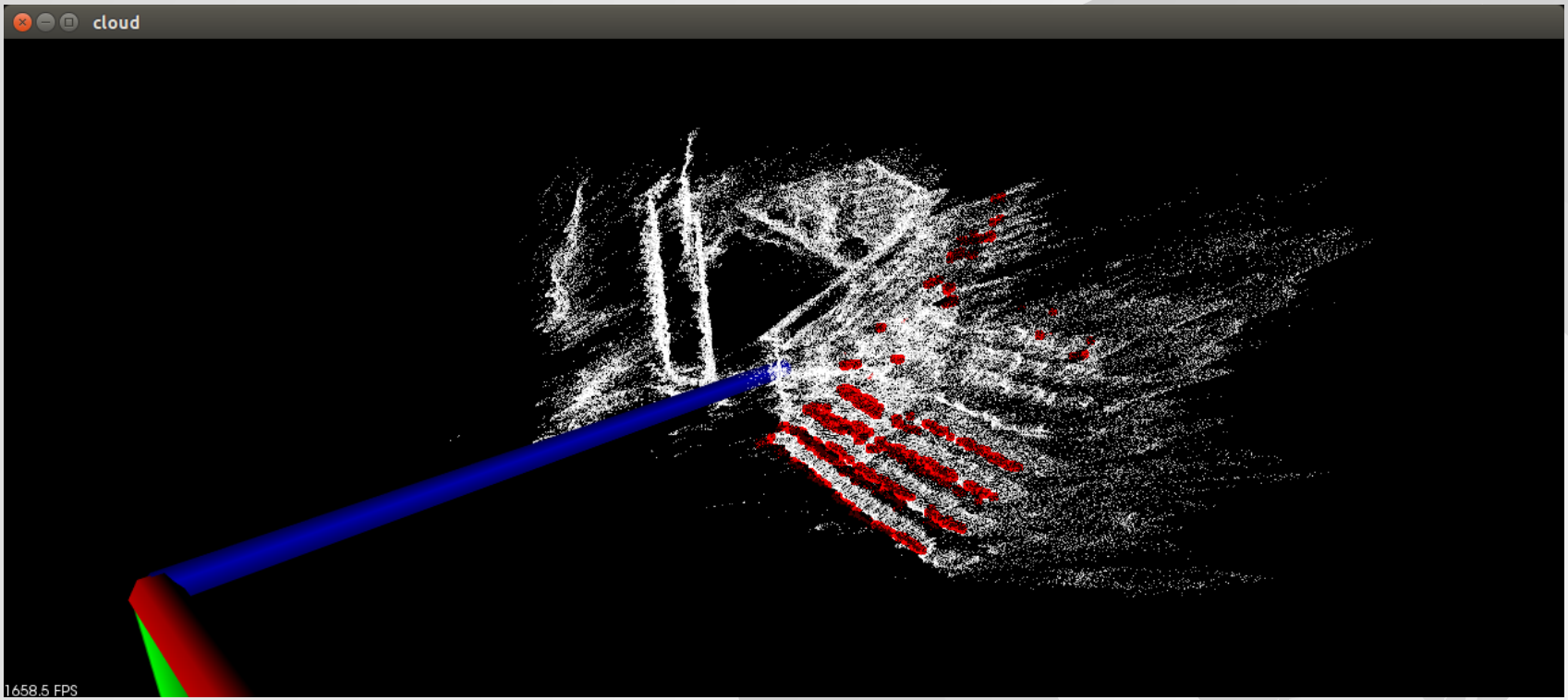
- depth image

Fusion

- 3D line
- 3D plane

take decision

Line and plane detection



2D detection

- line detection
- object detection
- line clipping

3D detection

- depth image

Fusion

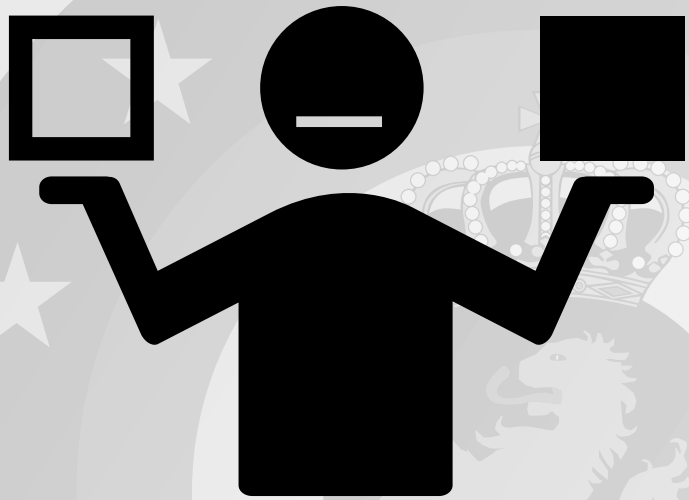
- 3D line
- 3D plane

Take decision

- parameters

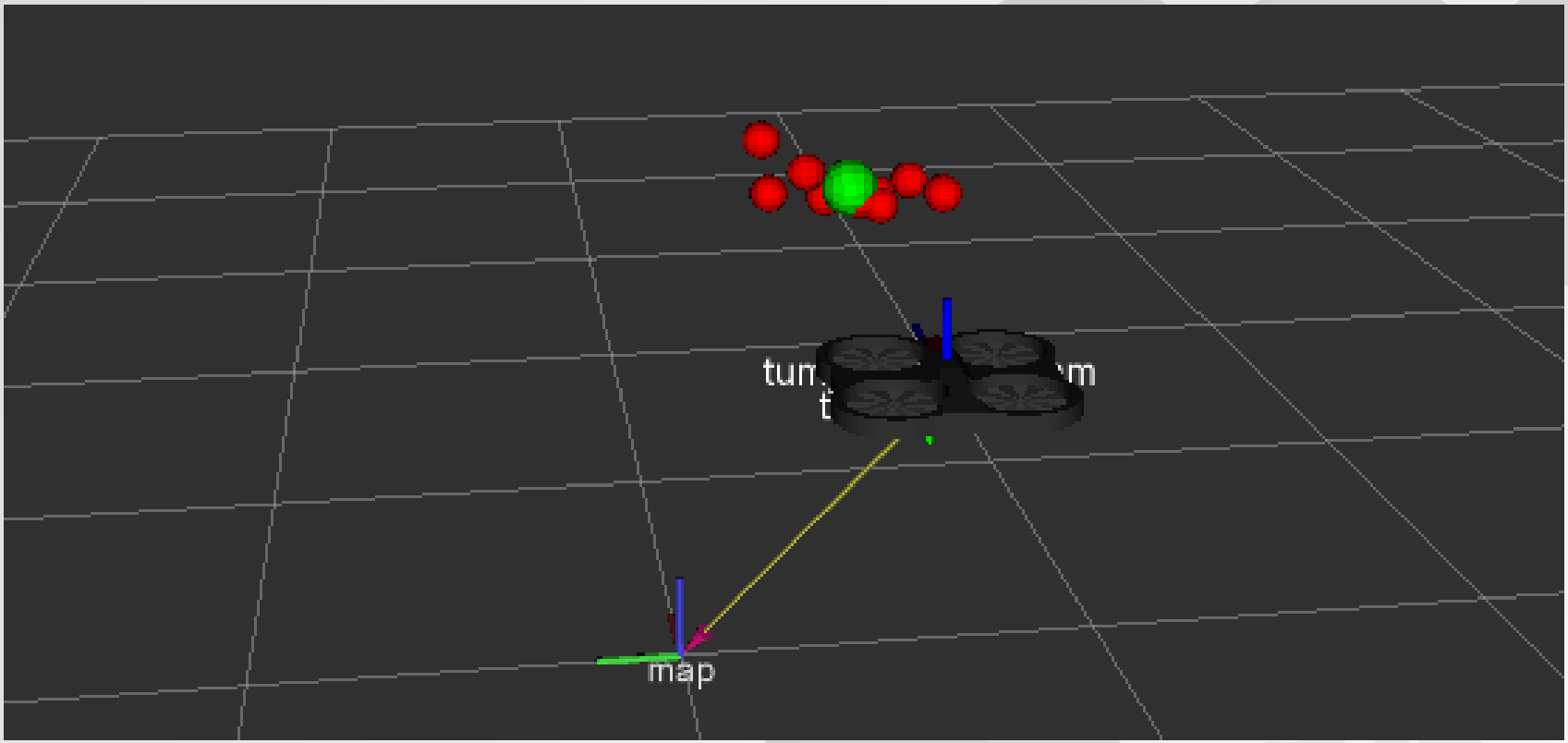
Decision parameters

- Minimum ♯ of lines
- Plane orientation
- Size of detected plane



Temporal consistency

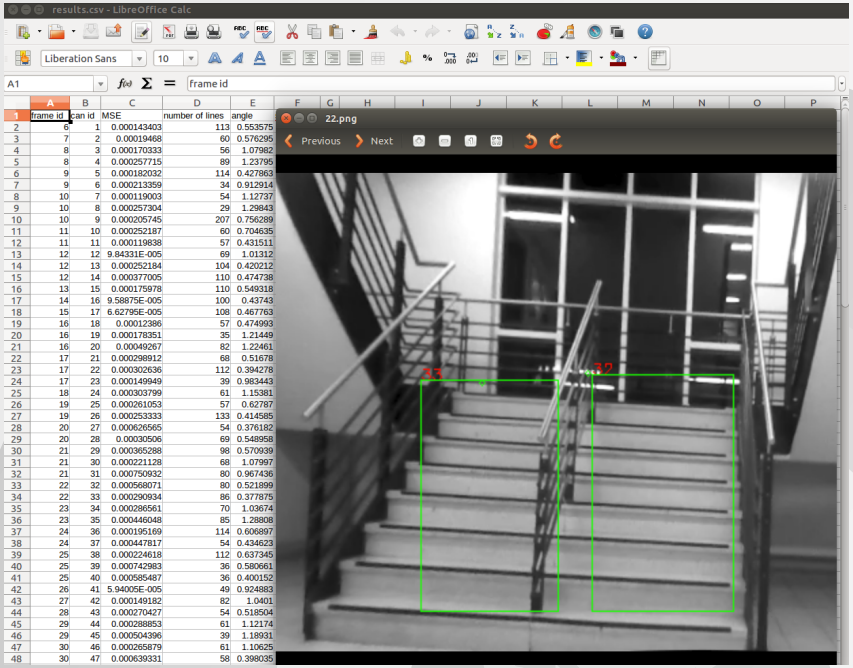
Bottom up hierarchical clustering → Agglomerative clustering



Evaluation

Algorithms were experimentally evaluated with

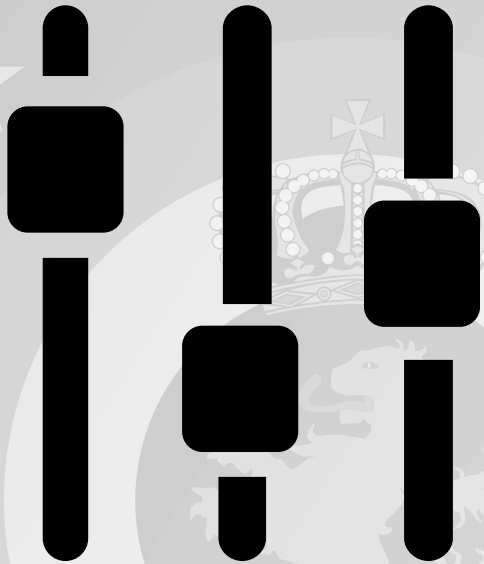
- ROS-bag of a staircase recording
- Multiple intermediary output parameters → CSV files
- Trial and error

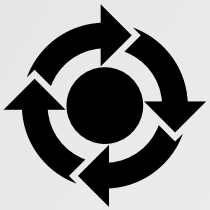


frame id	can id	MSE	number of lines	angle
6	1	0.000143403	113	0.553575
7	2	0.00019468	60	0.576295
8	3	0.000170333	56	1.07982
8	4	0.000257715	89	1.23795
9	5	0.000182032	114	0.427863
9	6	0.000213359	34	0.912914
10	7	0.000119003	54	1.12737
10	8	0.000257304	29	1.29843
10	9	0.000205745	207	0.756289
11	10	0.000252187	60	0.704635
11	11	0.000119838	57	0.431511
12	12	9.84331E-005	69	1.01312
12	13	0.000252184	104	0.420212
12	14	0.000377005	110	0.474738
13	15	0.000175978	110	0.549318
14	16	9.58875E-005	100	0.43743
15	17	6.62795E-005	108	0.467763
16	18	0.00012386	57	0.474993
16	19	0.000178351	35	1.21449
16	20	0.00049267	82	1.22461
17	21	0.000298912	68	0.51678
17	22	0.000302636	112	0.394278
17	23	0.000149949	39	0.983443
18	24	0.000303799	61	1.15381
19	25	0.000261053	57	0.62787
19	26	0.000253333	133	0.414585
20	27	0.000626565	54	0.376182
20	28	0.00030506	69	0.548958
21	29	0.000365288	98	0.570939
21	30	0.000221128	68	1.07997
21	31	0.000750932	80	0.967436
22	32	0.000568071	80	0.521899
22	33	0.000290934	86	0.377875
23	34	0.000286561	70	1.03674
23	35	0.000446048	85	1.28808
24	36	0.000195169	114	0.606897
24	37	0.000447817	54	0.434623
25	38	0.000224618	112	0.637345
25	39	0.000742983	36	0.580661
25	40	0.000585487	36	0.400152
26	41	5.94005E-005	49	0.924883
27	42	0.000149182	82	1.0401
28	43	0.000270427	54	0.518504
29	44	0.000288853	61	1.12174
29	45	0.000504396	39	1.18931
30	46	0.000265879	61	1.10625
30	47	0.000639331	58	0.398035

Modifications

- Programmed interface to use produced 3D data
- Removed OpenCV 2 dependencies
- Automatic re-initialization is implemented after *Tracking lost*
- Changed default parameters LSD-SLAM





PID controller Graphical User Interface

Positioning

- TUM AR.Drone
- EKF

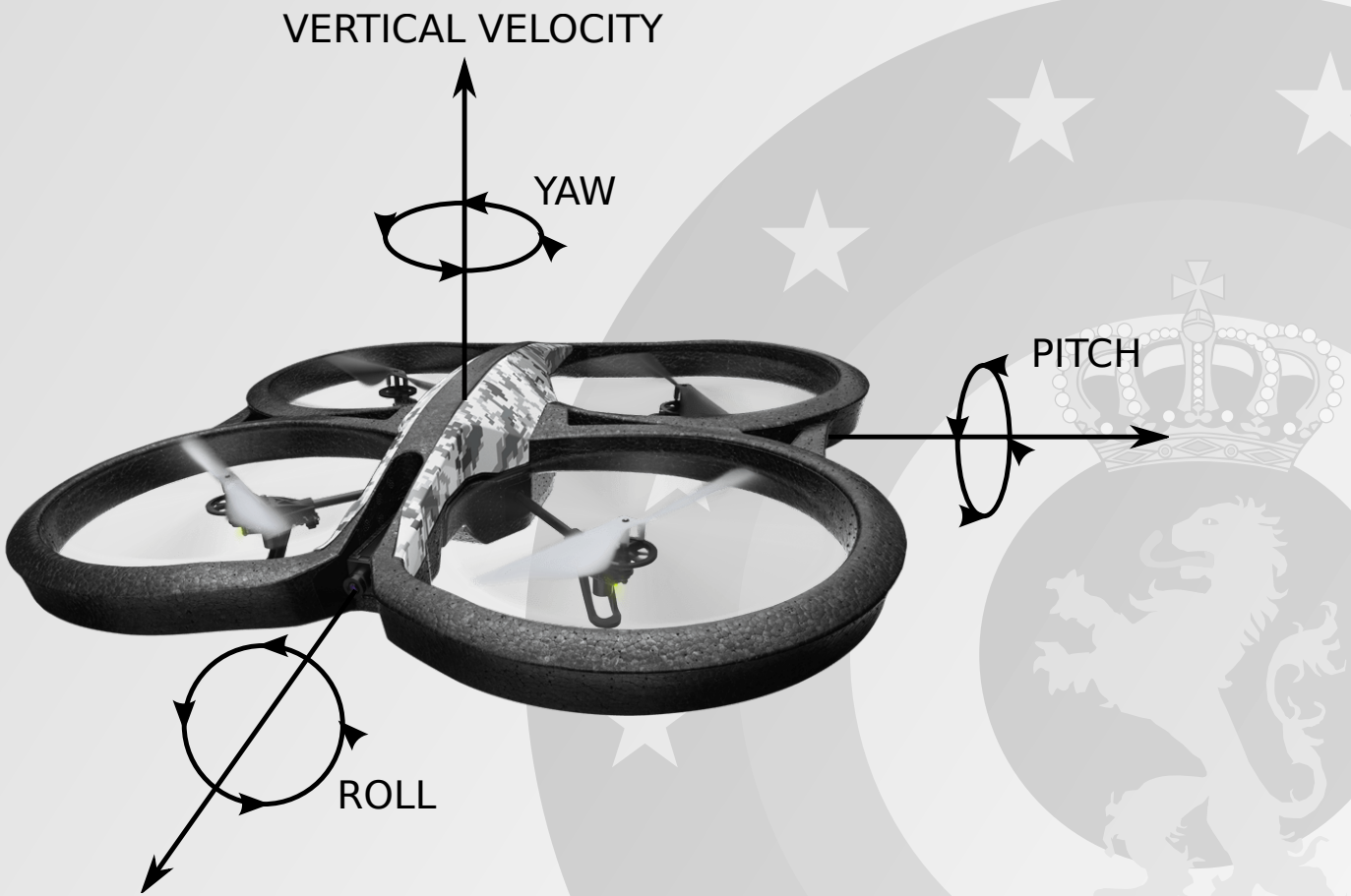
Understand Environment

- SLAM
- Detection

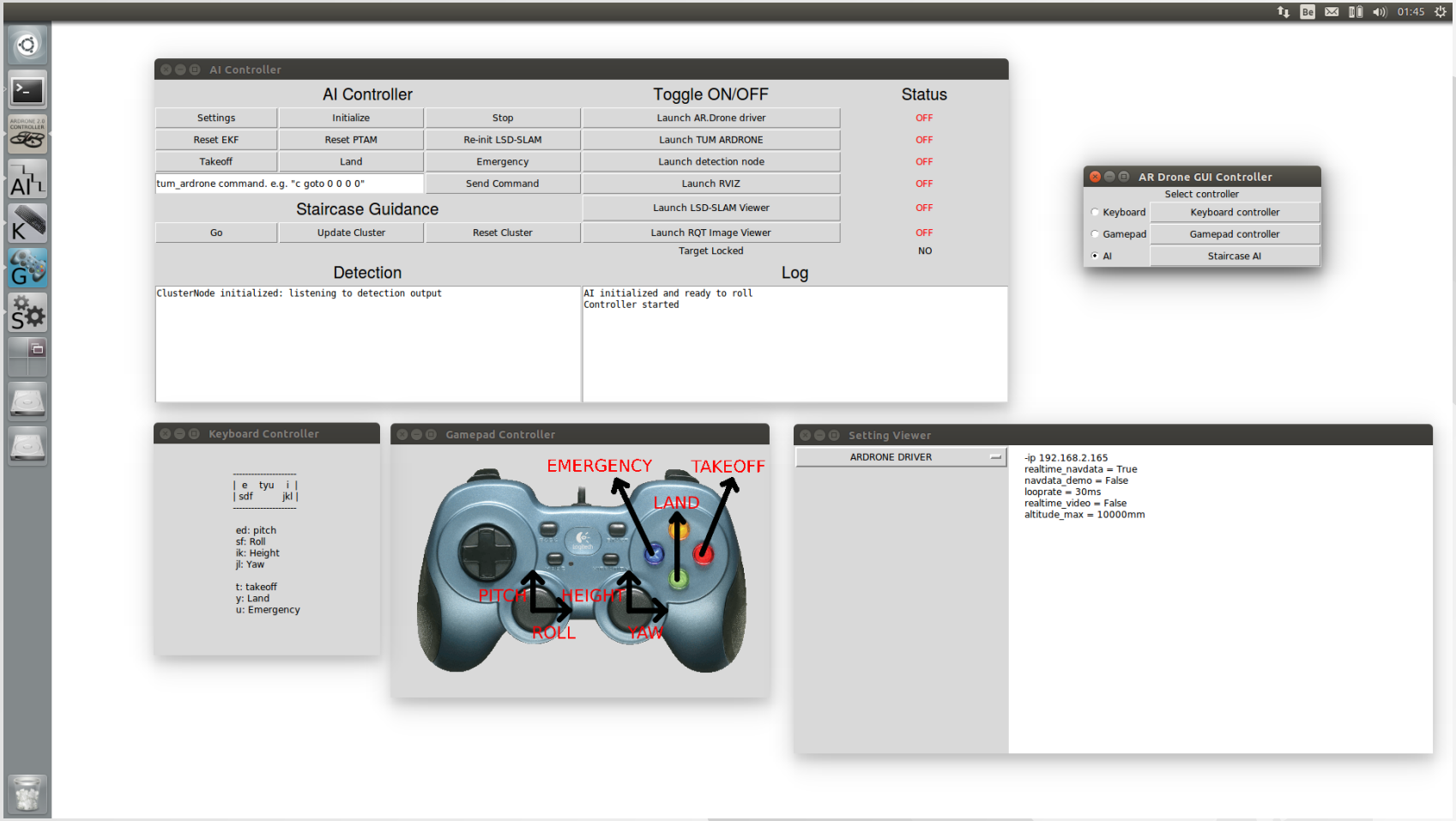
Control

- PID controller
- Staircase AI

4 Degrees of freedom



GUI windows


AI Controller
AI Controller
Toggle ON/OFF
Status
Settings
Initialize
Stop
Launch AR.Drone driver
OFF
Reset EKF
Reset PTAM
Re-init LSD-SLAM
Launch TUM ARDRONE
OFF
Takeoff
Land
Emergency
Launch detection node
OFF
tum_ardrone command. e.g. "c goto 0 0 0 0"
Send Command
Launch RVIZ
OFF
Staircase Guidance
Launch LSD-SLAM Viewer
OFF
Go
Update Cluster
Reset Cluster
Launch RQT Image Viewer
OFF
Target Locked
NO
Detection
Log
ClusterNode initialized: listening to detection output
AI initialized and ready to roll
Controller started
AR Drone GUI Controller
Select controller
Keyboard
Keyboard controller
Gamepad
Gamepad controller
AI
Staircase AI
Keyboard Controller
| e tyu i |
| sdf jkl |
ed: pitch
sf: Roll
ik: Height
jl: Yaw
t: takeoff
y: Land
u: Emergency
Gamepad Controller
EMERGENCY
TAKEOFF
LAND
PITCH
HEIGHT
ROLL
YAW
Setting Viewer
ARDRONE DRIVER
-ip 192.168.2.165
realtime_navdata = True
navdata_demo = False
looprate = 30ms
realtime_video = False
altitude_max = 10000mm

PID controller Graphical User Interface

Staircase AI

AI Controller

AI Controller			Toggle ON/OFF	Status
Settings	Initialize	Stop	Launch AR.Drone driver	OFF
Reset EKF	Reset PTAM	Re-init LSD-SLAM	Launch TUM ARDRONE	OFF
Takeoff	Land	Emergency	Launch detection node	OFF
tum_ardrone command. e.g. "c goto 0 0 0 0"		Send Command	Launch RVIZ	OFF
Staircase Guidance			Launch LSD-SLAM Viewer	OFF
Go	Update Cluster	Reset Cluster	Launch RQT Image Viewer	OFF
			Target Locked	NO

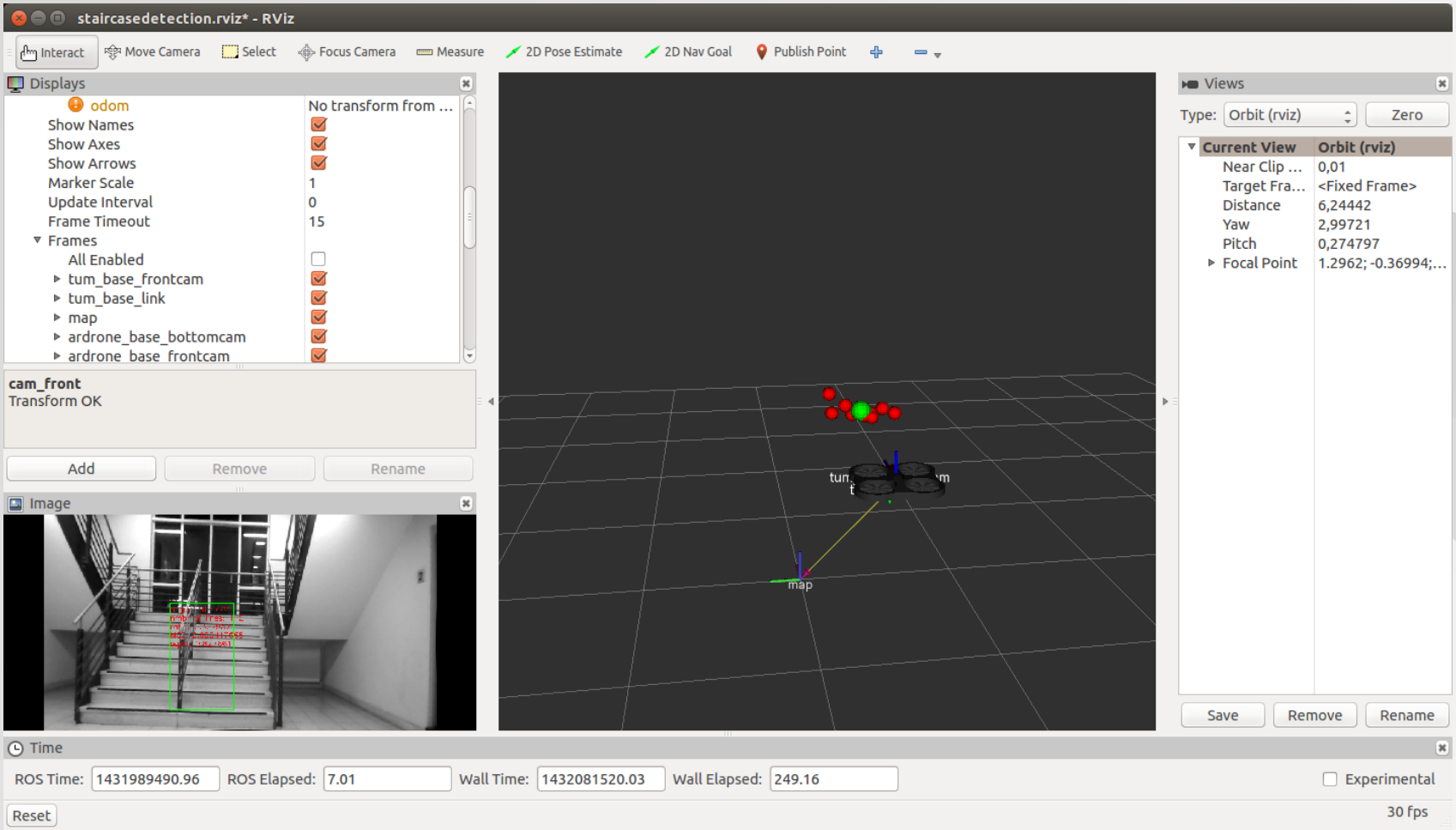
Detection

```
ClusterNode initialized: listening to detection output
```

Log

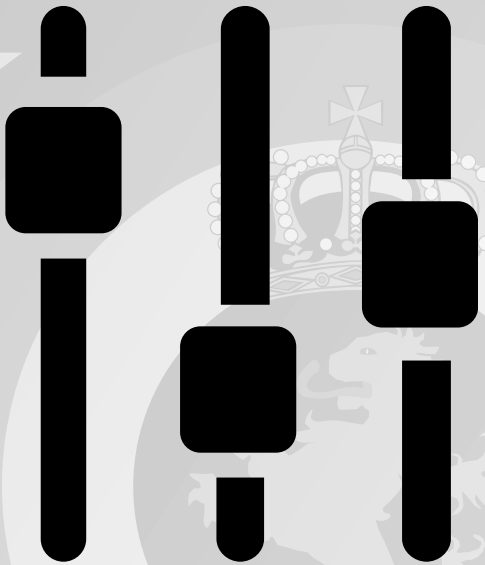
```
AI initialized and ready to roll
Controller started
```

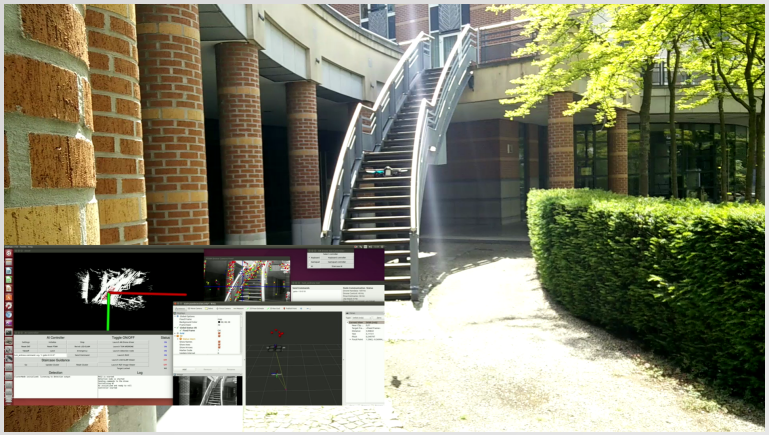

.be

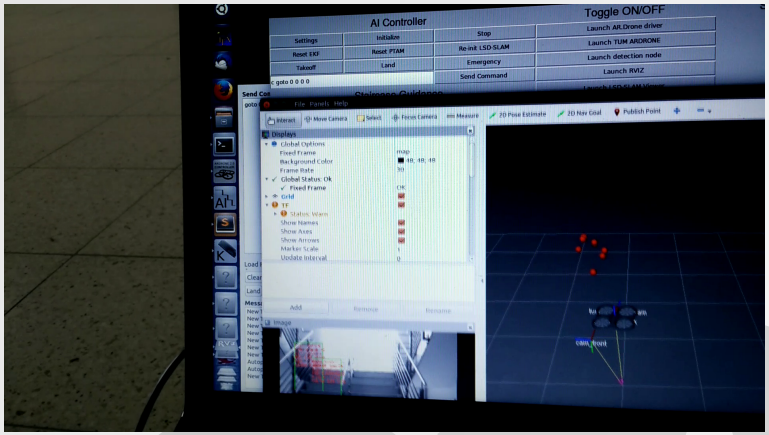

staircasedetection.rviz* - RViz
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Nav Goal
Publish Point
Displays
odom
No transform from ...
Show Names
Show Axes
Show Arrows
Marker Scale
1
Update Interval
0
Frame Timeout
15
Frames
All Enabled
tum_base_frontcam
tum_base_link
map
ardrone_base_bottomcam
ardrone_base_frontcam
cam_front
Transform OK
Add
Remove
Rename
Image
map
Views
Type:
Orbit (rviz)
Zero
Current View
Orbit (rviz)
Near Clip ...
0,01
Target Fra...
<Fixed Frame>
Distance
6,24442
Yaw
2,99721
Pitch
0,274797
Focal Point
1.2962; -0.36994;...
Save
Remove
Rename
Time
ROS Time:
1431989490.96
ROS Elapsed:
7.01
Wall Time:
1432081520.03
Wall Elapsed:
249.16
Experimental
Reset
30 fps

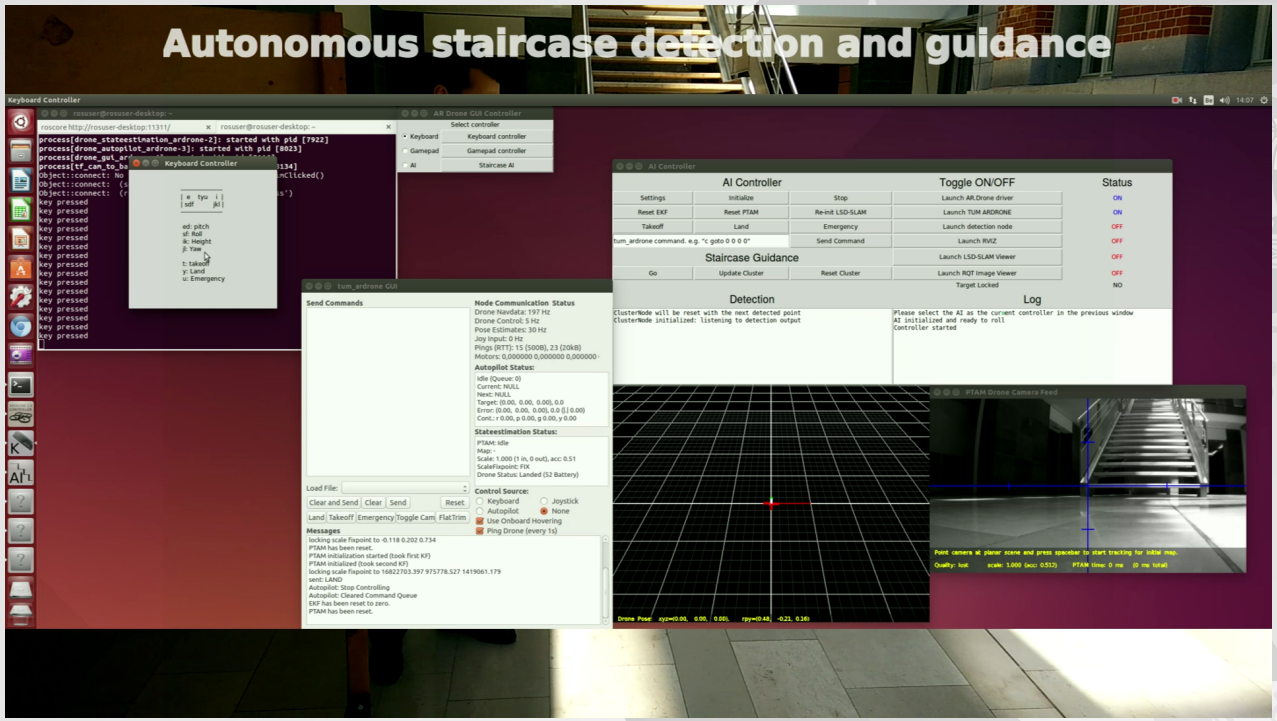
Modifications

- Reset service LSD-SLAM is added
- New keyboard controls
- Parameter tuning: **aggressiveness**






AI Controller
Toggle ON/OFF
Settings
Initialize
Stop
Launch AR.Drone driver
Reset EKF
Reset PTAM
Re-init LSD-SLAM
Launch TUM ARDRONE
Takeoff
Land
Emergency
Launch detection node
Send Command
Launch RVIZ


Autonomous staircase detection and guidance
Keyboard Controller
AR Drone GUI Controller
AI Controller
Toggle ON/OFF
Status
Staircase Guidance
Detection
Log
tum_ardrone GUI
PTAM Drone Camera Feed

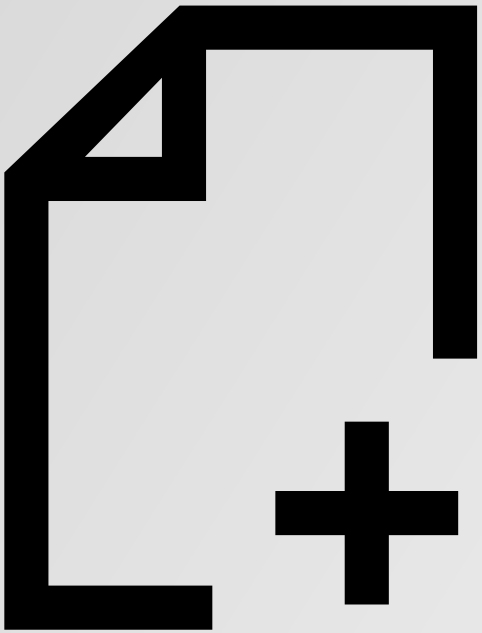
Problems

Stumbling blocks

- Precision position estimation → EKF on-board
- Manual initialization PTAM → new SLAM algorithm
- Unstability Tum AR.Drone → More sensors, on-board
- Low quality 3D data → better camera / different sensor

Problems

What this thesis implemented

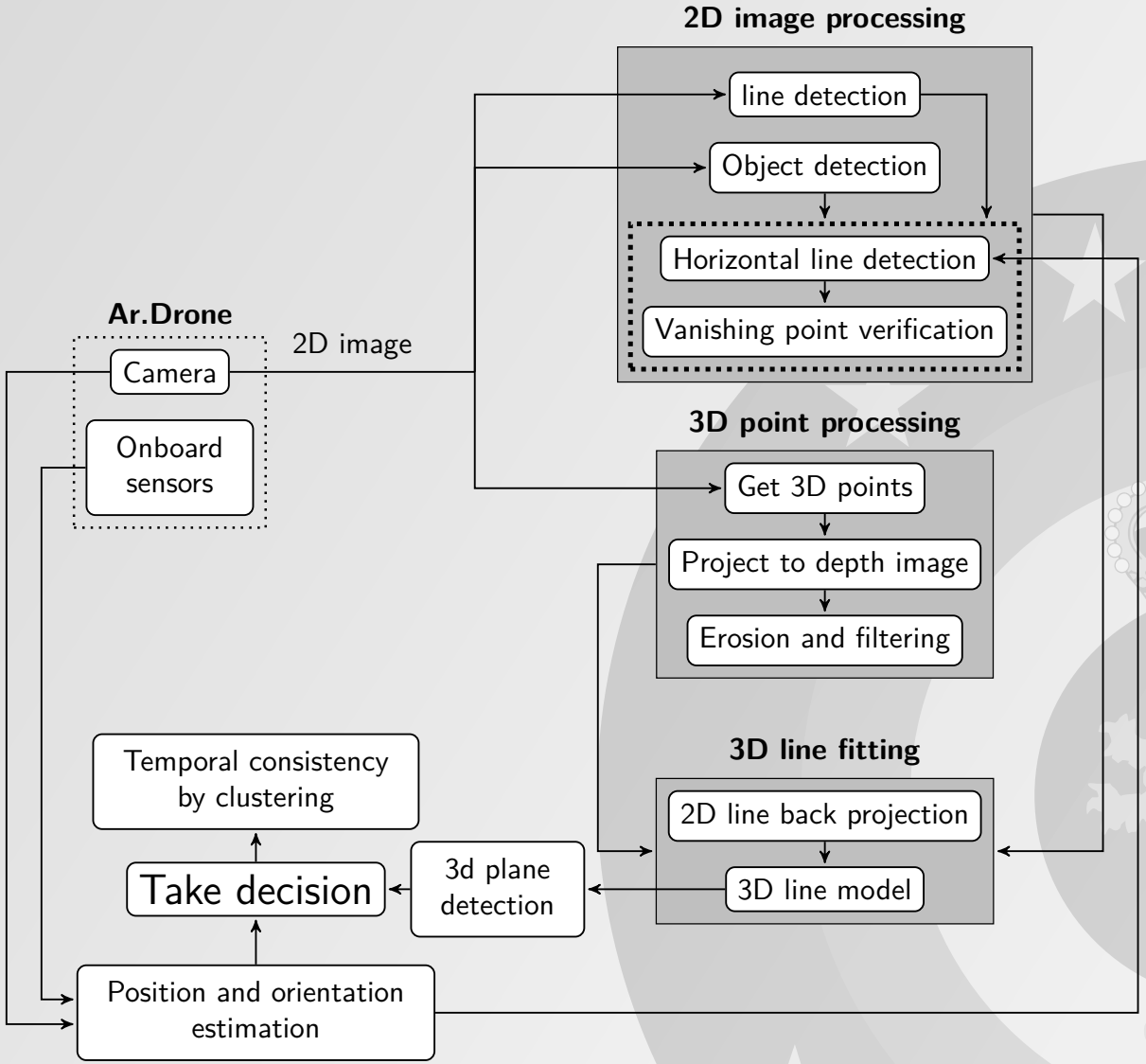


- Unique fusion of different existing algorithms
- Practical use of different SLAM algorithms
- Easy to use GUI for testing and debugging
- Near real-time operational software
- Extensively documented reproducible approach

Problems

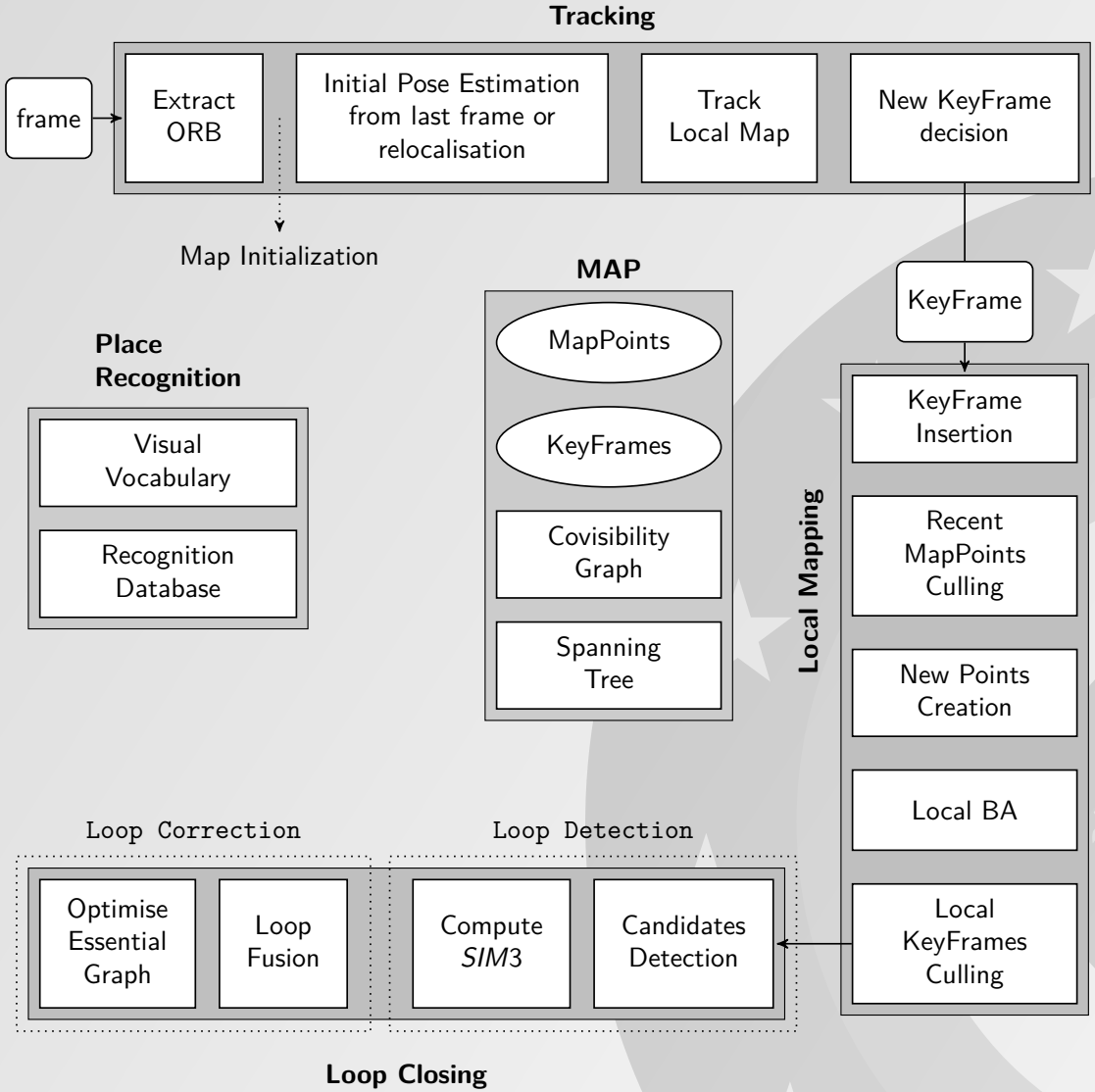
Questions?

Schematic overview



Return

ORB-SLAM



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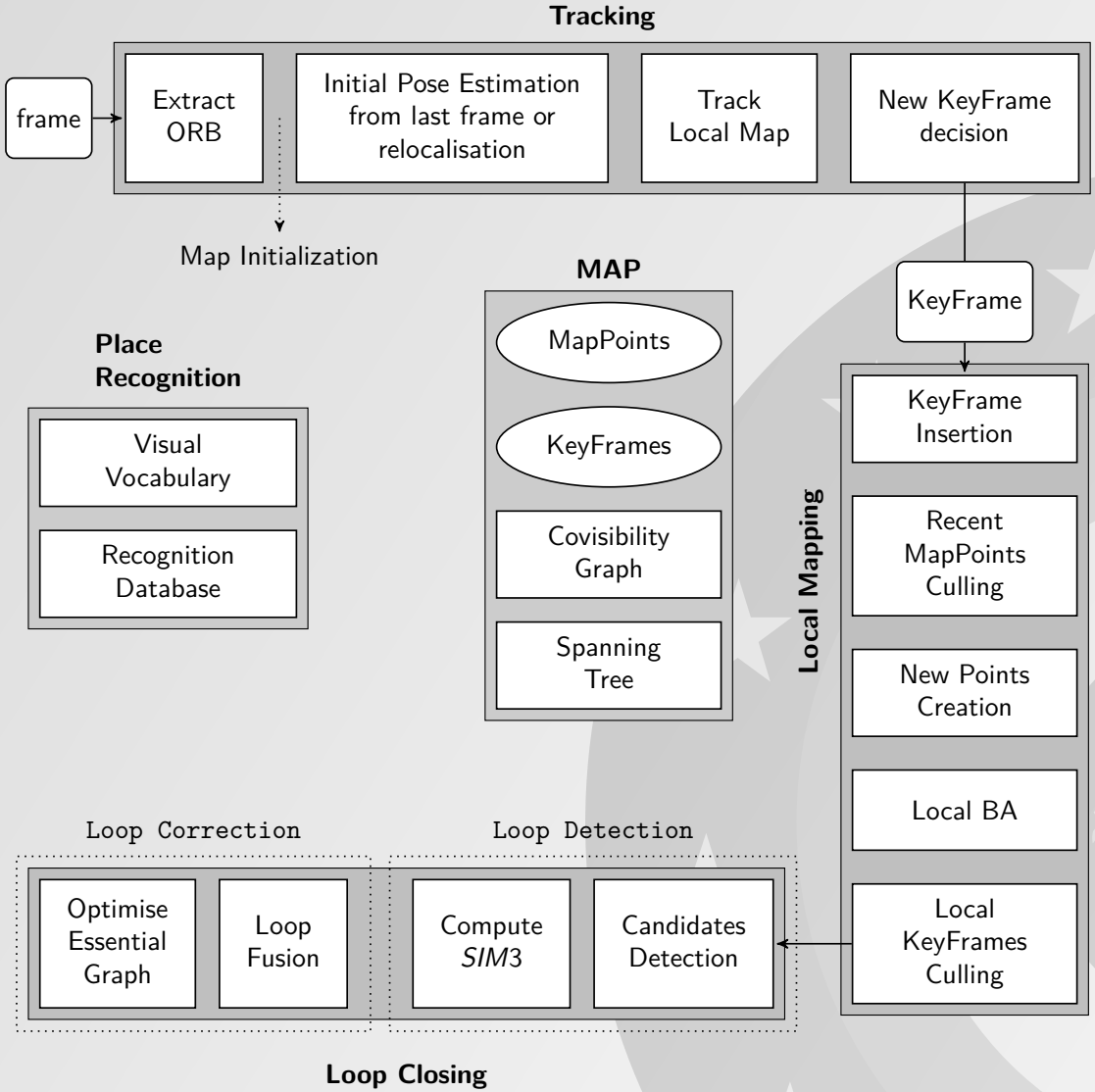
ORB-SLAM



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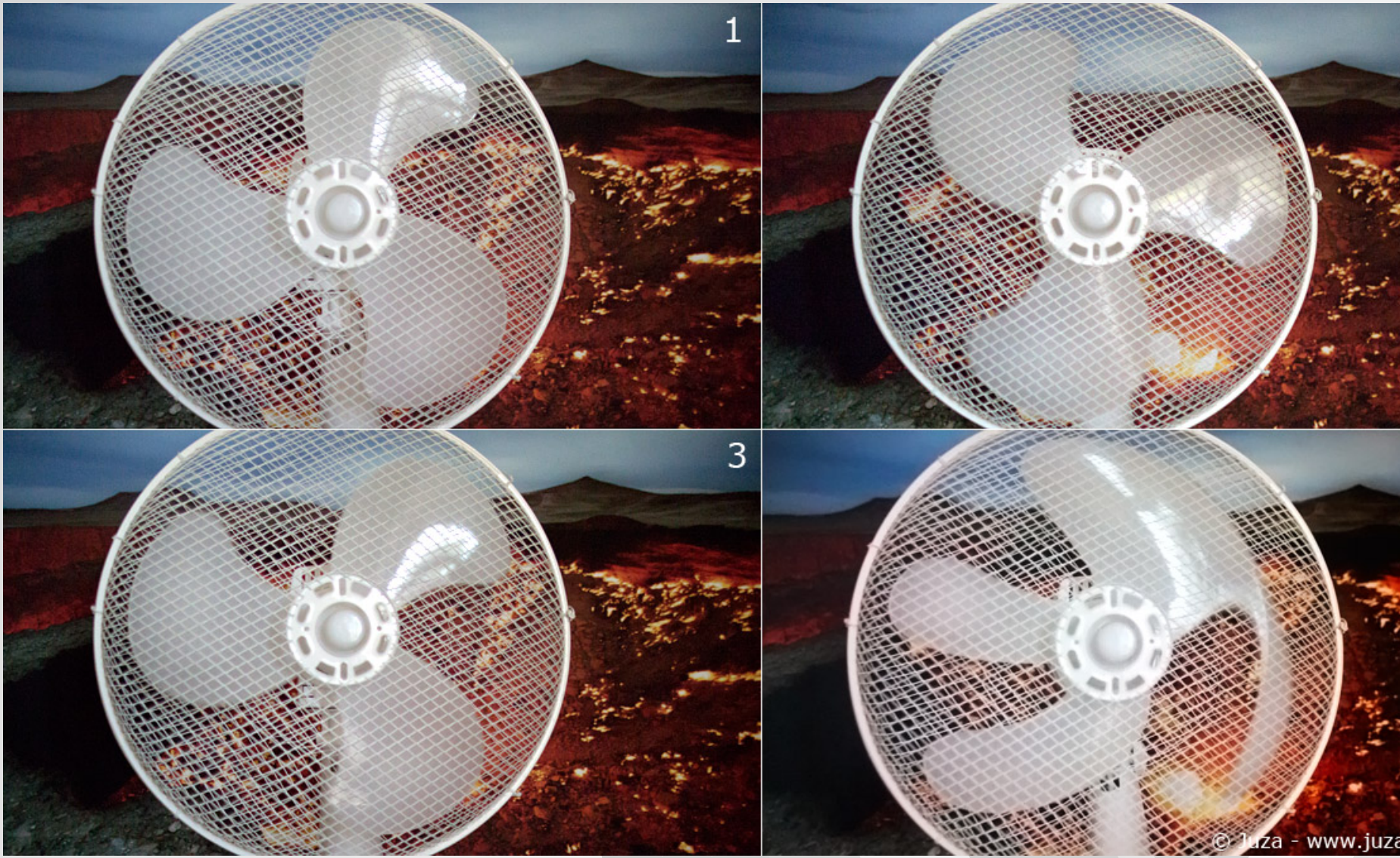
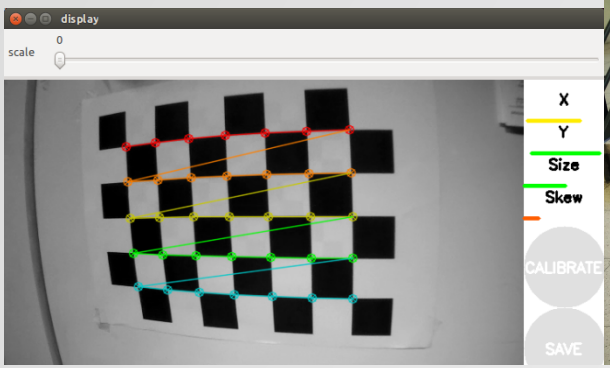
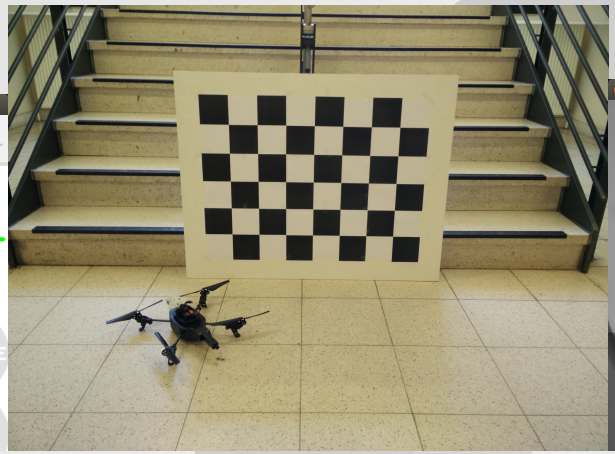


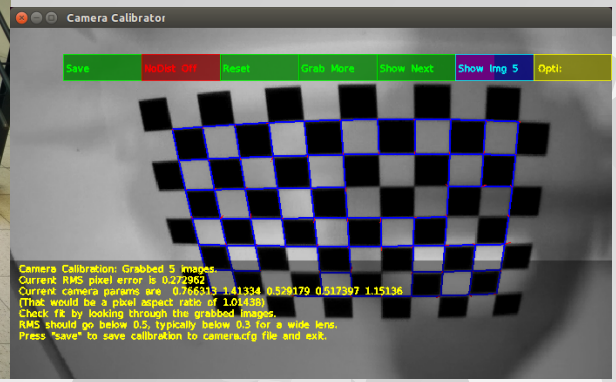
Return

Juza. "Electronic VS mechanical shutter". In: (June 12, 2014). URL: http://www.juzaphoto.com/article.php?l=en&t=mechanical_and_electronic_shutter (visited on 05/21/2015)

Camera callibration







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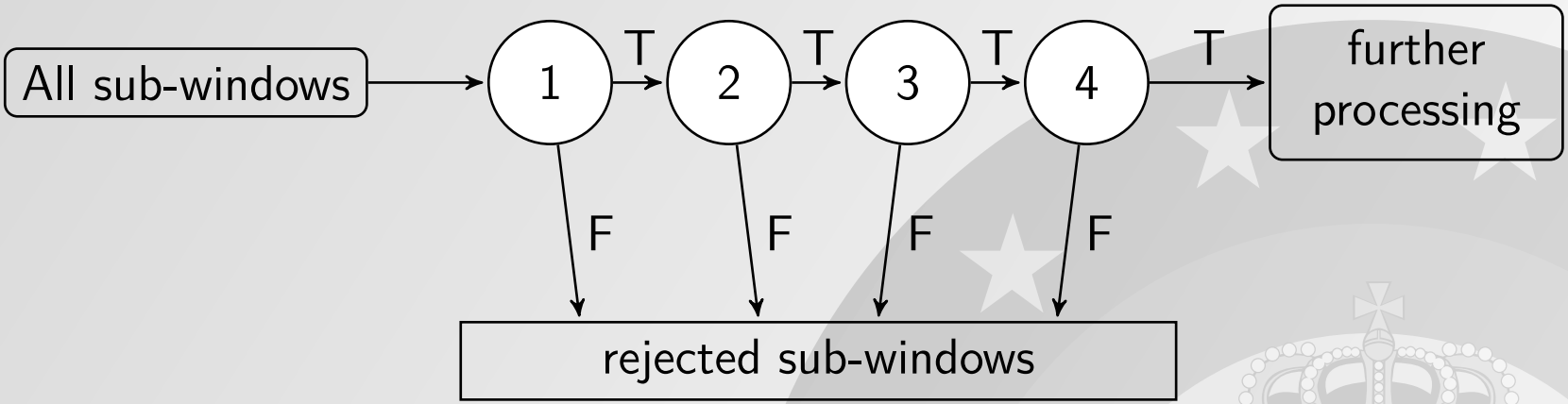
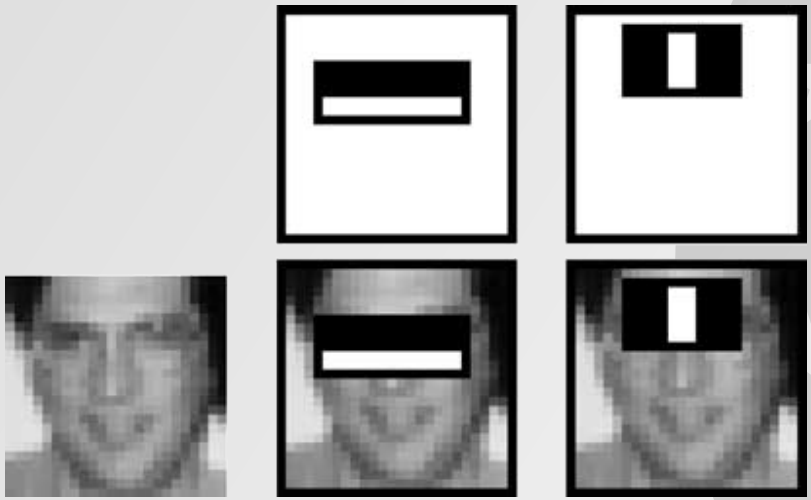
Object detection





Paul Viola and Michael Jones. "Robust real-time object detection". In: *International Journal of Computer Vision* 4 (2001), pp. 34–47

Cohen Sutherland

further explication line clipping

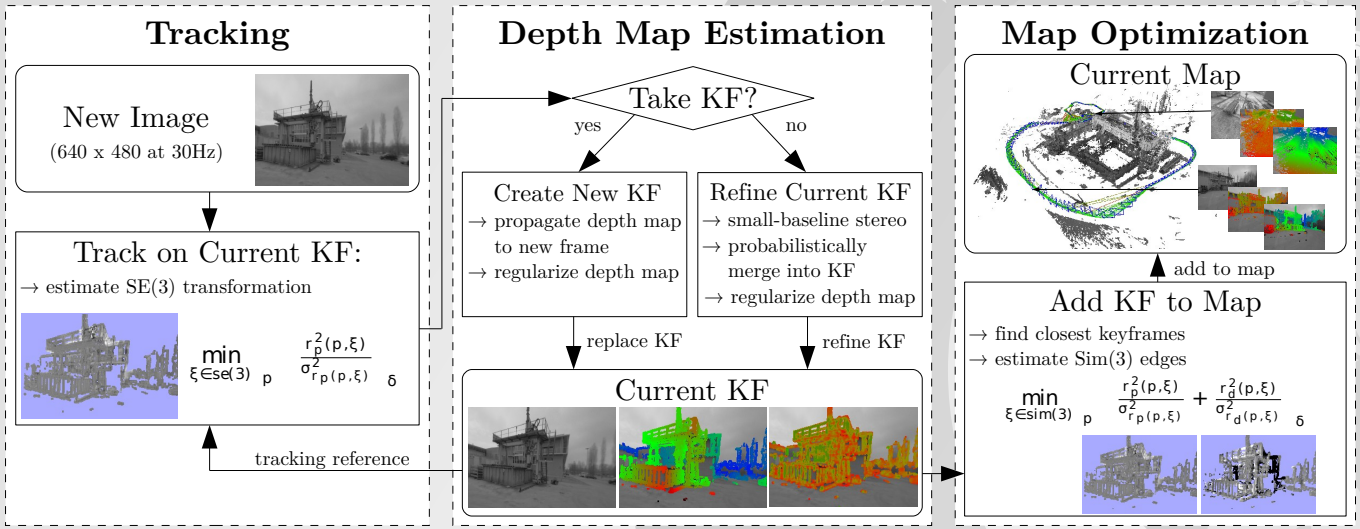
Return

Hough transform

content... Return

LSD-SLAM

- Auto-initialization
- CPU-based
- Creates semi-dense depth-images



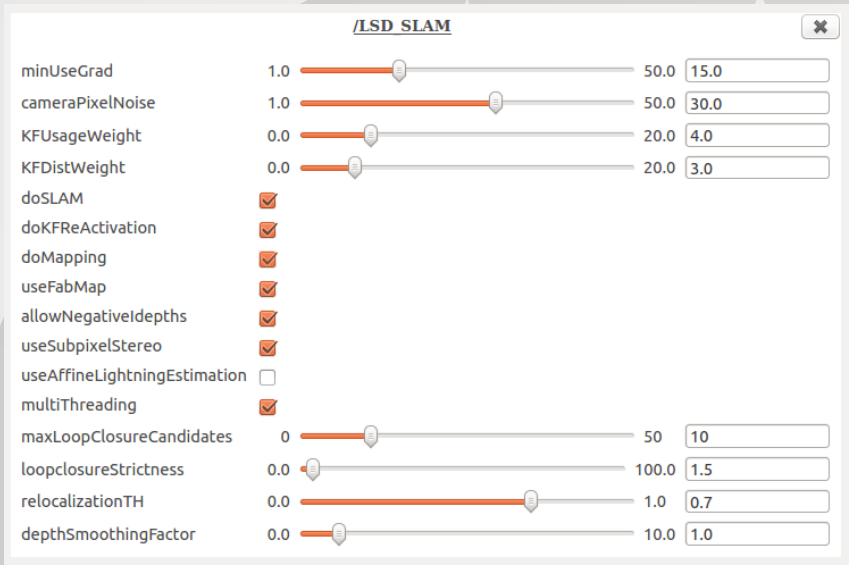
Return

Parameter tuning LSD-SLAM

Three interesting parameters:

- **minUseGrad**
  Default: 5 - Set to 15
- **cameraPixelNoise**
  Default: 4 - Set to 30
- **depthSmoothingFactor**
  Default: 1 - Unchanged

Especially the **cameraPixelNoise** is an important parameter.

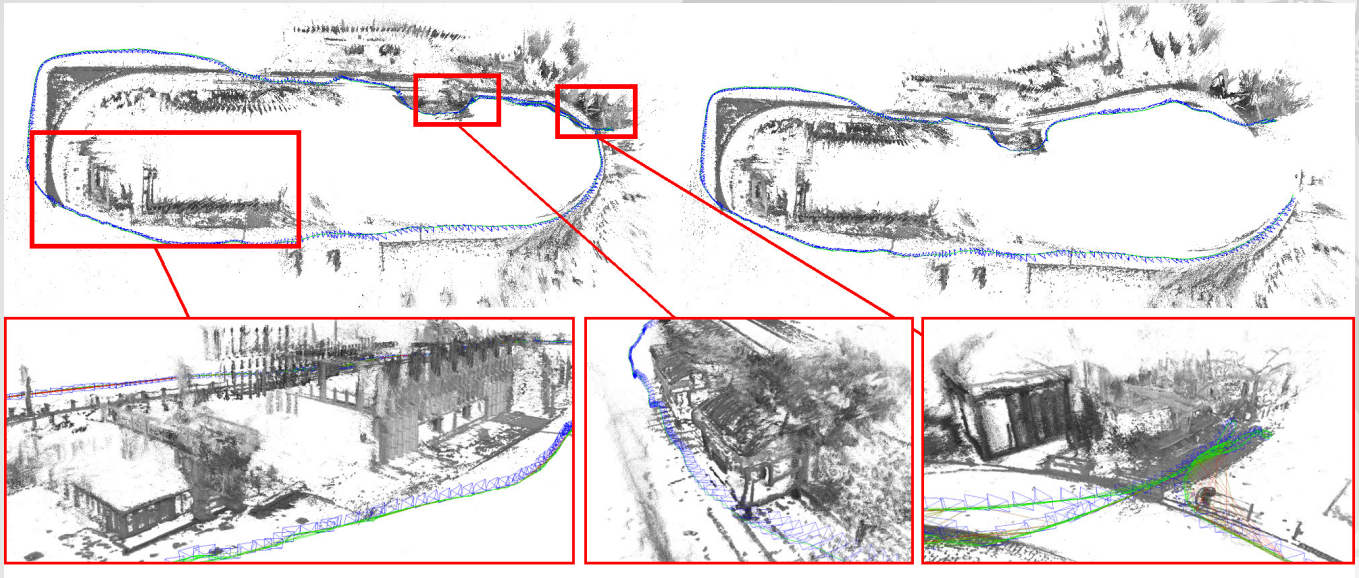


Return

Scale estimation LSD-SLAM

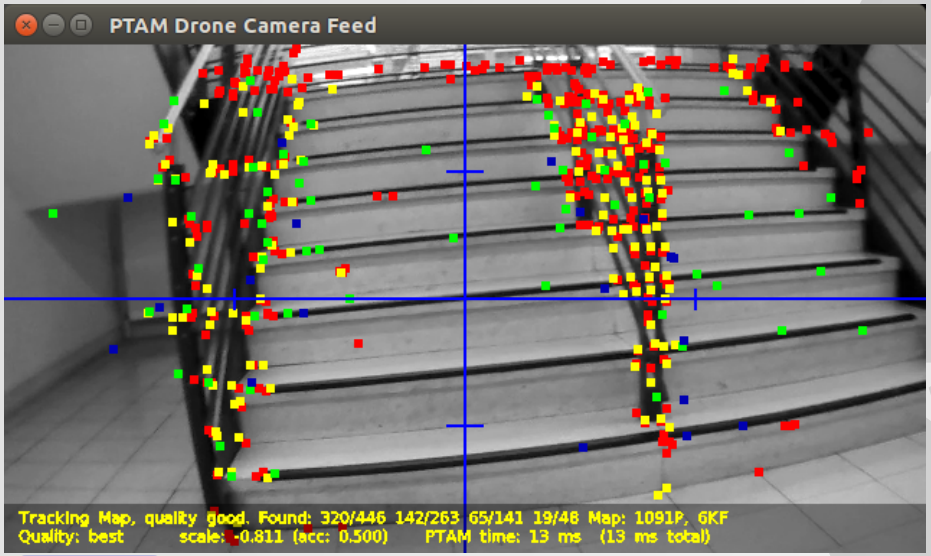
Integrated image alignment technique that is scale-drift aware:

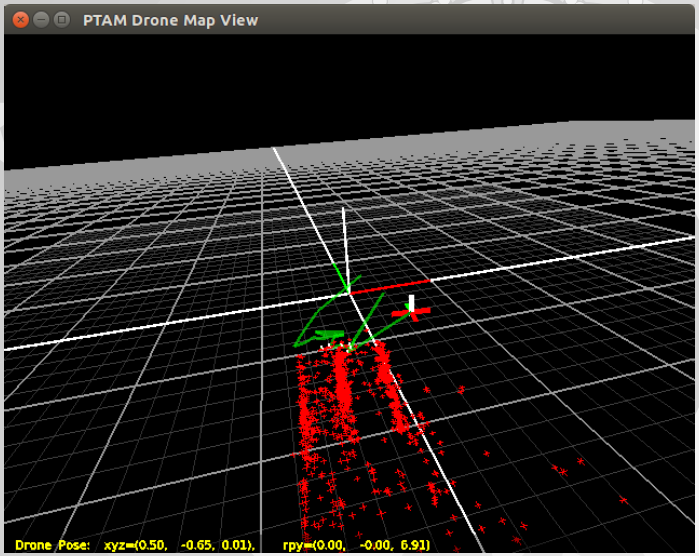
- Uses inherent correlation between:
  - Scene depth
  - Tracking accuracy



PTAM

- One of the first feature-based SLAM algorithms
- Tracking + Mapping in two threads
- Manual initialization process
- Fully integrated in TUM AR.Drone





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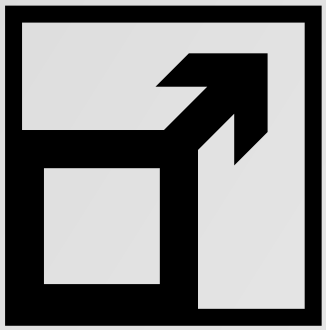
Scale estimation PTAM

The TUM AR.Drone package estimates the scale using a maximum likelihood estimator based on:

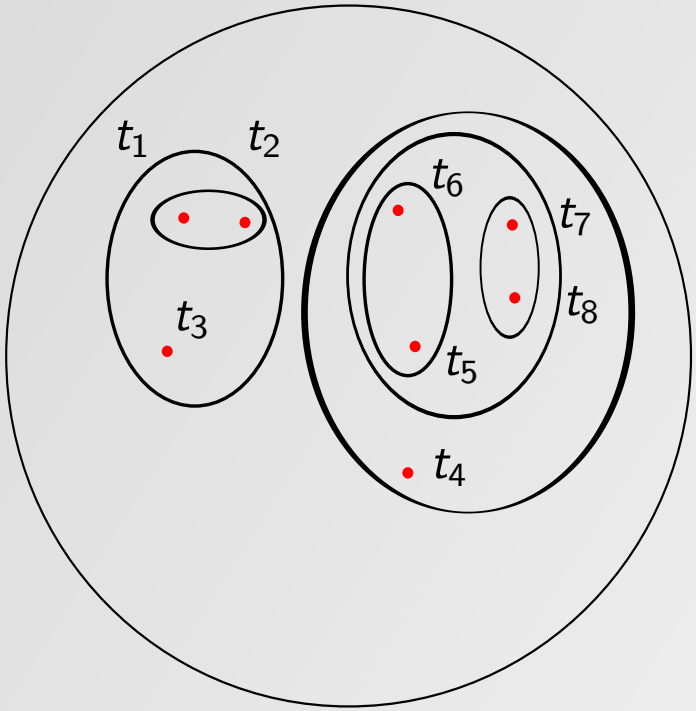


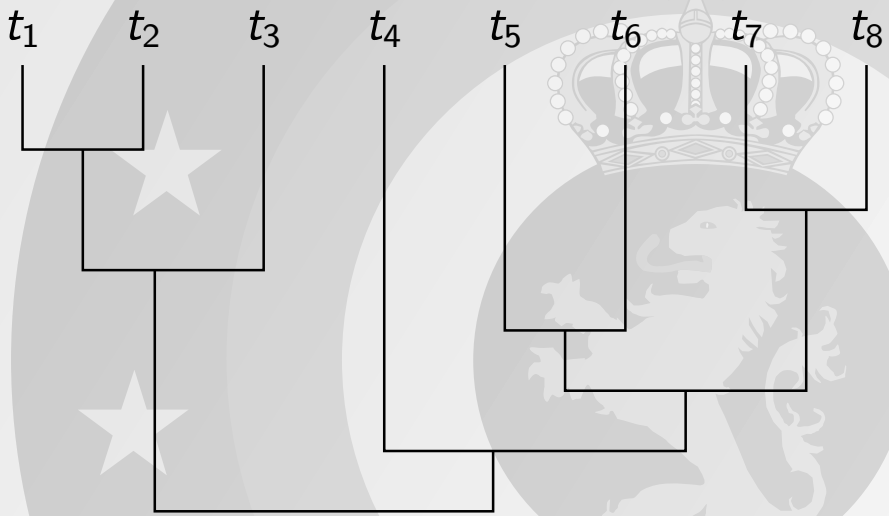
- $x_i \in \mathbb{R}^d$ - the d-dimensional distance according to PTAM
- $y_i \in \mathbb{R}^d$ - the absolute distance/velocity provided by the metric sensors.

The linear approximation of the scale λ is derived from

$$x_i \approx \lambda y_i$$

Hierarchical clustering





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