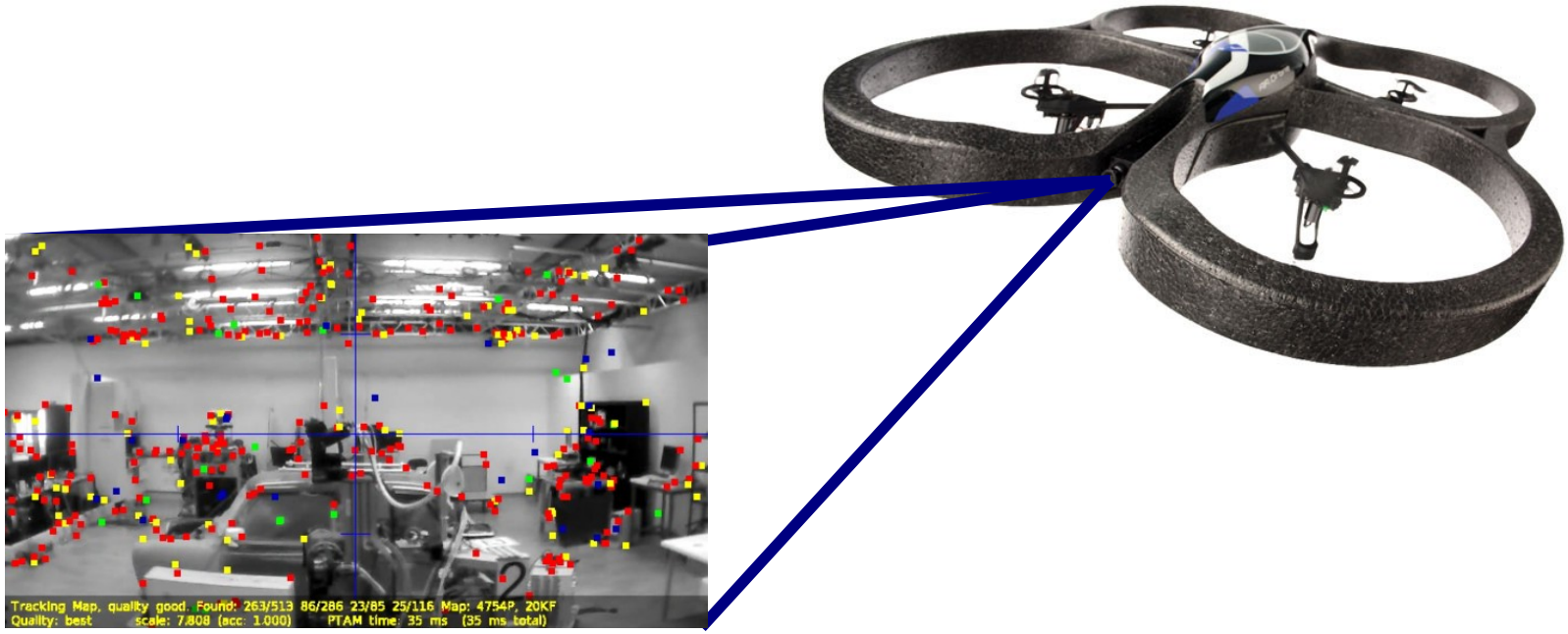
Autonomous Navigation of Small-Scale Quadrocopters

Jakob Engel

VisNav invited talk, 25.06.2013



How to make the AR.Drone fly more stable?

1. time delays
2. marker → PTAM

1. Time Delays

capture frame → send to PC → compute → send control

takes 150ms - 250ms

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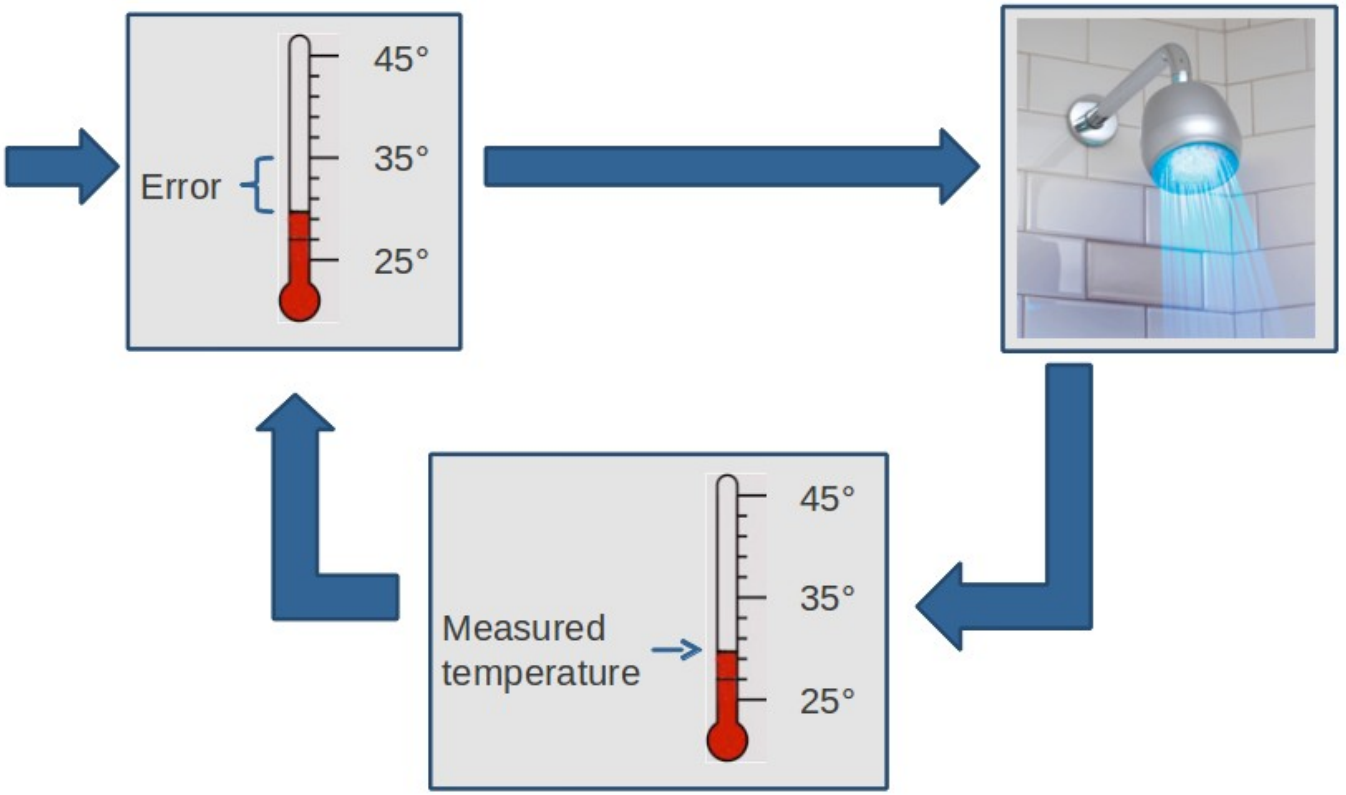
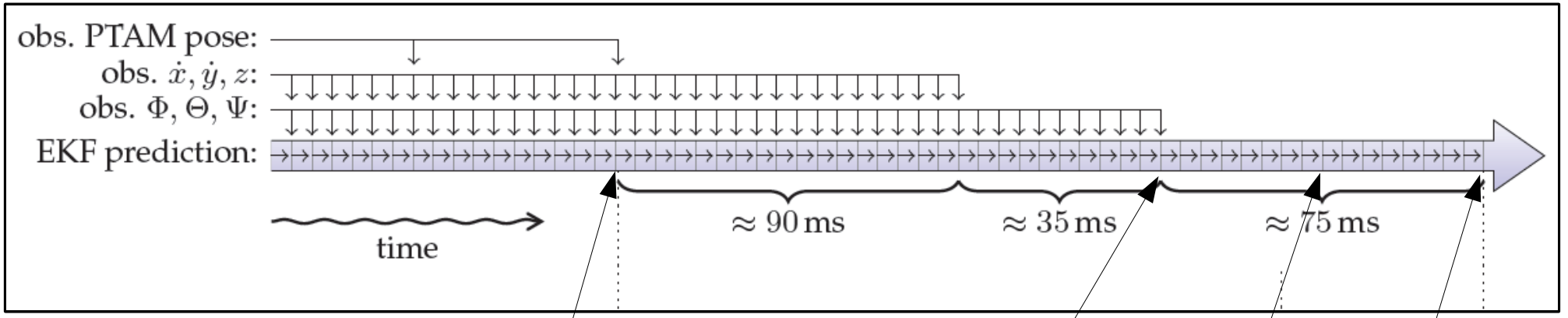


Solution: Explicitly model delays



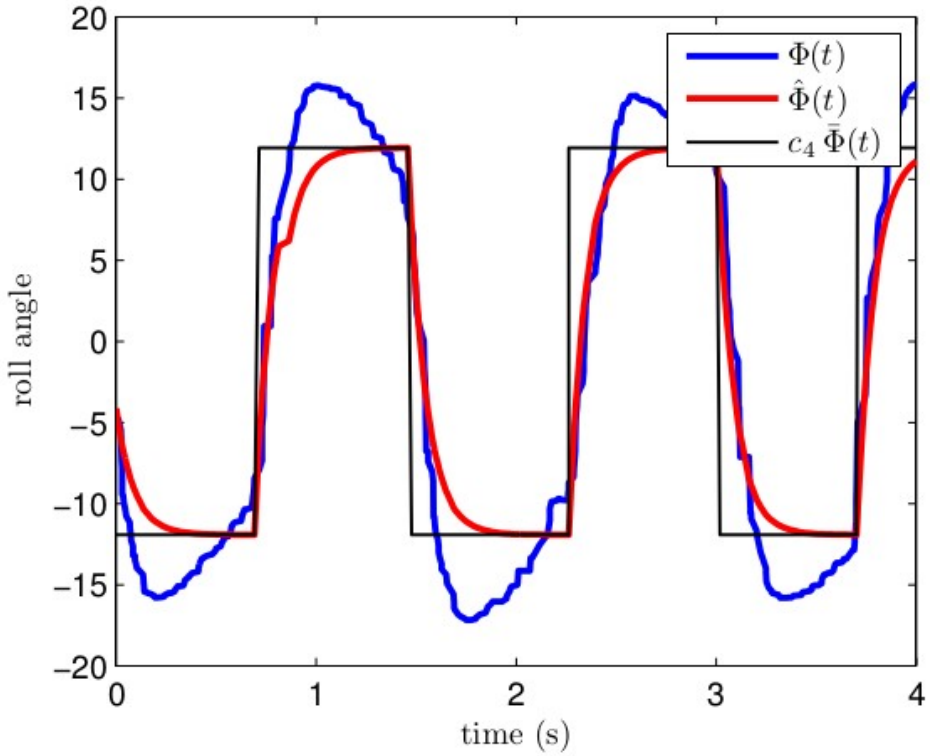
last visual observation

last IMU observation

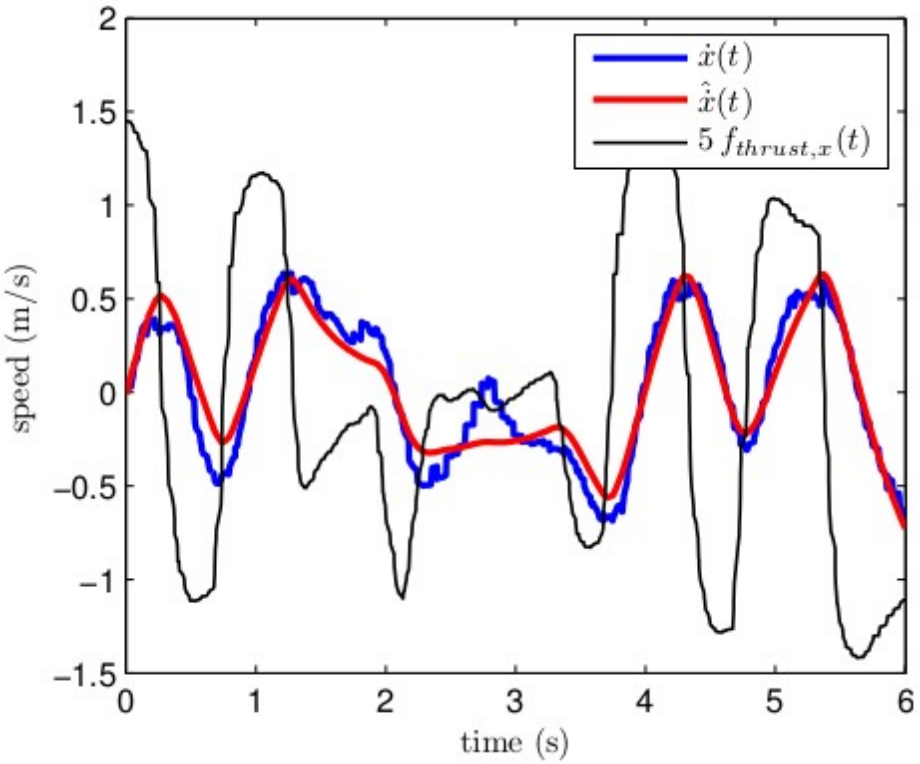
now

drone will receive control

Solution: Model control & dynamics



control → attitude



attitude → velocity

→ enables fully “blind” prediction

Full EKF

$$\begin{pmatrix} x_{t+1} \\ y_{t+1} \\ z_{t+1} \\ \dot{x}_{t+1} \\ \dot{y}_{t+1} \\ \dot{z}_{t+1} \\ \Phi_{t+1} \\ \Theta_{t+1} \\ \Psi_{t+1} \\ \dot{\Psi}_{t+1} \end{pmatrix} \leftarrow \begin{pmatrix} x_t \\ y_t \\ z_t \\ \dot{x}_t \\ \dot{y}_t \\ \dot{z}_t \\ \Phi_t \\ \Theta_t \\ \Psi_t \\ \dot{\Psi}_t \end{pmatrix} + \delta_t \begin{pmatrix} \dot{x}_t \\ \dot{y}_t \\ \dot{z}_t \\ \ddot{x}(\mathbf{x}_t) \\ \ddot{y}(\mathbf{x}_t) \\ \ddot{z}(\mathbf{x}_t, \mathbf{u}_t) \\ \dot{\Phi}(\mathbf{x}_t, \mathbf{u}_t) \\ \dot{\Theta}(\mathbf{x}_t, \mathbf{u}_t) \\ \dot{\Psi}_t \\ \ddot{\Psi}(\mathbf{x}_t, \mathbf{u}_t) \end{pmatrix}$$

$$\dot{\Phi}(\mathbf{x}_t, \mathbf{u}_t) = c_3 \bar{\Phi}_t - c_4 \Phi_t$$
$$\dot{\Theta}(\mathbf{x}_t, \mathbf{u}_t) = c_3 \bar{\Theta}_t - c_4 \Theta_t$$
$$\ddot{\Psi}(\mathbf{x}_t, \mathbf{u}_t) = c_5 \bar{\dot{\Psi}}_t - c_6 \dot{\Psi}_t$$
$$\ddot{z}(\mathbf{x}_t, \mathbf{u}_t) = c_7 \bar{\dot{z}}_t - c_8 \dot{z}_t$$
$$\ddot{x}(\mathbf{x}_t) = c_1 (\cos\Psi_t \sin\Phi_t \cos\Theta_t - \sin\Psi_t \sin\Theta_t) - c_2 \dot{x}_t$$
$$\ddot{y}(\mathbf{x}_t) = c_1 (-\sin\Psi_t \sin\Phi_t \cos\Theta_t - \cos\Psi_t \sin\Theta_t) - c_2 \dot{y}_t$$

EKF Prediction

$$h_{\text{PTAM}}(\mathbf{x}) := (x, y, z, \Phi, \Theta, \Psi)^T \in \mathbb{R}^6$$
$$\mathbf{z}_{\text{PTAM}} := \log(\mathbf{E}_{\mathcal{DC}} \mathbf{E}_{\mathcal{C}}) \in \mathbb{R}^6$$

PTAM Observation

$$h_{\text{IMU}}(\mathbf{x}) := \begin{pmatrix} \cos(\Psi)\dot{x} - \sin(\Psi)\dot{y} \\ \sin(\Psi)\dot{x} + \cos(\Psi)\dot{y} \\ z \\ \Phi \\ \Theta \\ \Psi \end{pmatrix} \in \mathbb{R}^6$$

$$\mathbf{z}_{\text{IMU}} := \begin{pmatrix} \dot{x}_d \\ \dot{y}_d \\ z(t-\delta_t) + h(t) - h(t-\delta_t) \\ \hat{\Phi} \\ \hat{\Theta} \\ \Psi(t-\delta_t) + \hat{\Psi}(t) - \hat{\Psi}(t-\delta_t) \end{pmatrix} \in \mathbb{R}^6$$

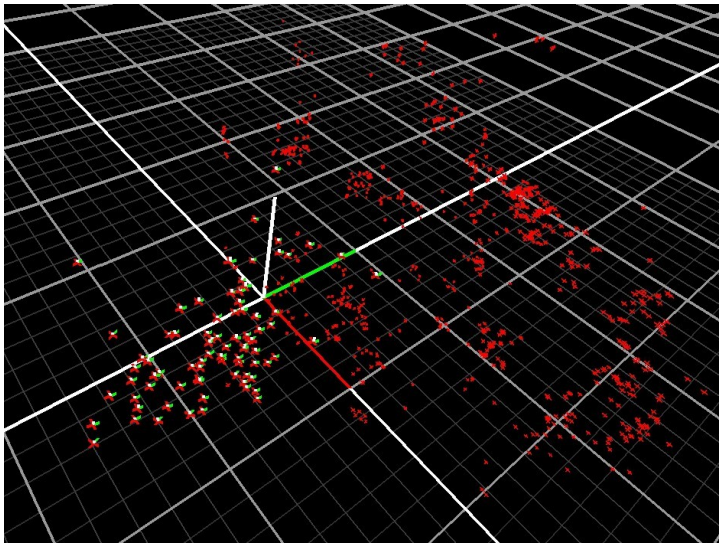
IMU, altimeter, velocity Observation

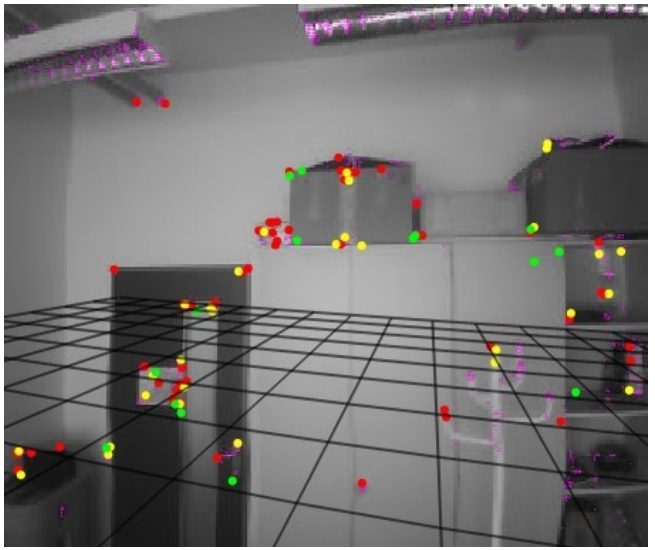
2. PTAM

Parallel Tracking and Mapping [Murray '07]:

→ keyframe based, monocular SLAM system

→ open-source





Problems: Unreliable, no scale

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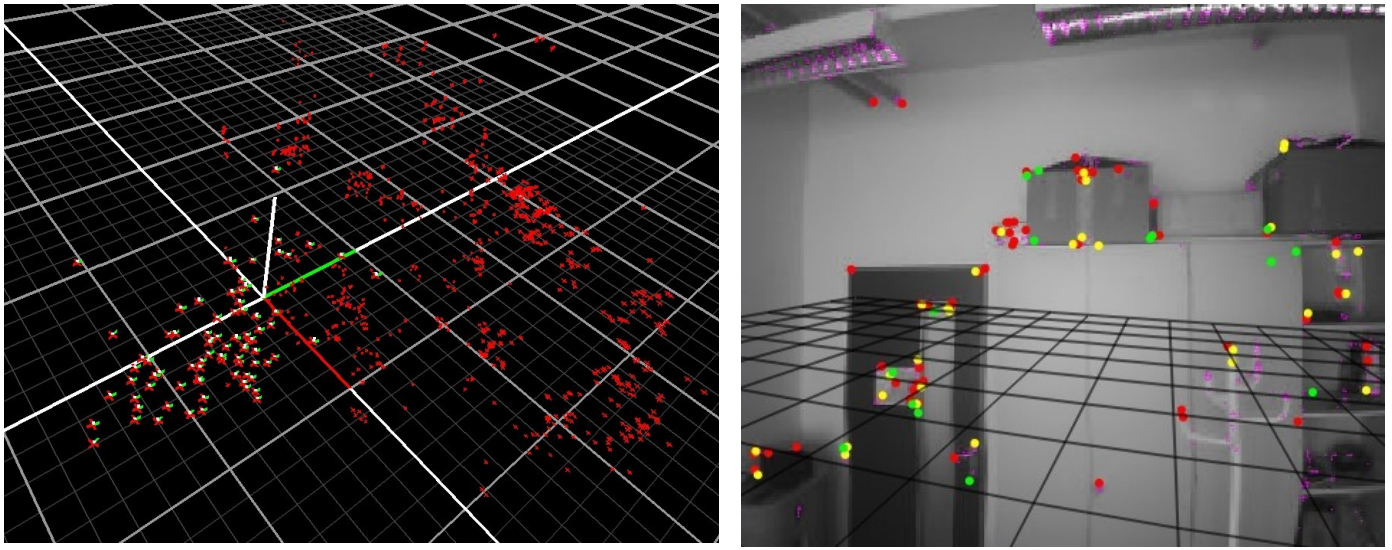
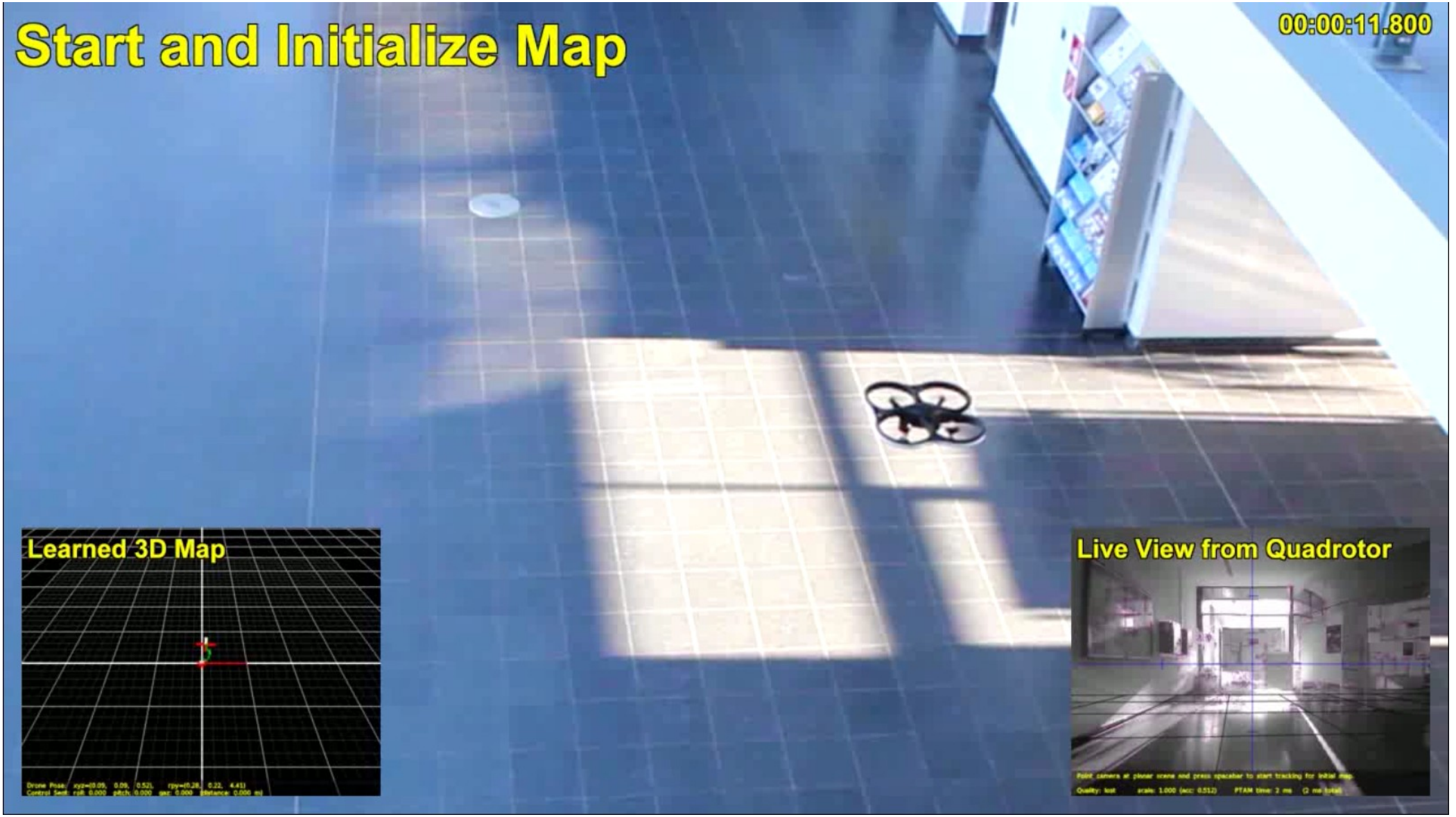


Problems: Unreliable, no scale

→ **enhance reliability** by incorporating IMU data

→ **add scale-estimation** from altimeter

2. PTAM


Start and Initialize Map
00:00:11.800
Learned 3D Map
Live View from Quadrotor

2. PTAM

tum_ardrone ROS package

tum_ardrone GUI

Send Commands

```
autoInit 500 800 4000 0.5

setReference $POSE$
setInitialReachDist 0.2
setStayWithinDist 0.3
setStayTime 3
lockScaleFP

goto 0 0 1 0
goto 0 0 0 0

goto -1 -1 0 0
goto -1 1 0 0
goto 1 1 0 0
goto 1 -1 0 0
goto -1 -1 1 0
goto -1 1 1 0
goto 1 1 1 0
goto 1 -1 1 0
goto 0 0 1 0
goto 0 0 0 0
```

Load File: jax.txt

Clear and Send | Clear | Send | Reset

Land | Takeoff | Emergency | Toggle Cam | FlatTrim

Node Communication Status

Drone Navdata: 199 Hz
Drone Control: 5 Hz
Pose Estimates: 30 Hz
Joy Input: 0 Hz
Pings (RTT): 21 (500B), 25 (20kB)
Motors: 0.000000 0.000000 0.000000

Autopilot Status:

Idle (Queue: 0)
Current: NULL
Next: NULL
Target: (0.00, 0.00, 0.00), 0.0
Error: (0.00, 0.00, 0.00), 0.0 (|.| 0.00)
Cont.: r 0.00, p 0.00, g 0.00, y 0.00

Stateestimation Status:

PTAM: Idle
Map: -
Scale: 1.000 (1 in, 0 out), acc: 0.51
ScaleFixpoint: FIX
Drone Status: Unknown (100 Battery)

Control Source:

○ Keyboard ○ Joystick
○ Autopilot ◉ None
☑ Use Onboard Hovering
☑ Ping Drone (every 1s)

Messages

```
PTAM has been reset.
PTAM initialization started (took first KF)
PTAM has been reset.
PTAM initialization started (took first KF)
PTAM has been reset.
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PTAM has been reset.
PTAM initialization started (took first KF)
PTAM has been reset.
```
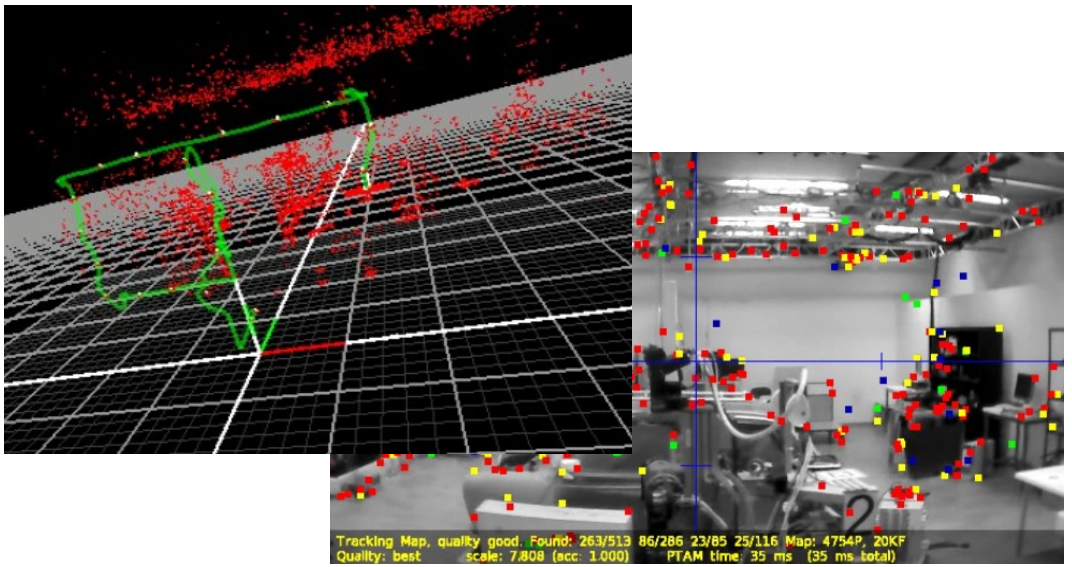

Node 1: GUI + backup control



Node 2: State-estimation (SLAM, EKF)

```
engelj@lapcremers38:~$ rosrun tum_ardrone drone_autopilot
[ INFO] [1369780328.885242358]: Started TUM ArDrone Autopilot Node.
set minPublishFreq to 110ms
```

Node 3: Autopilot (PID Controller)

Open Source @ www.ros.org/wiki/tum_ardrone

Future Work

- **Increase Range:**
  Augment PTAM with eg. FABMAP and/or g2o

- **Initialization:**
  Faster & more robust using gyro readings;
  Automatic re-initialization

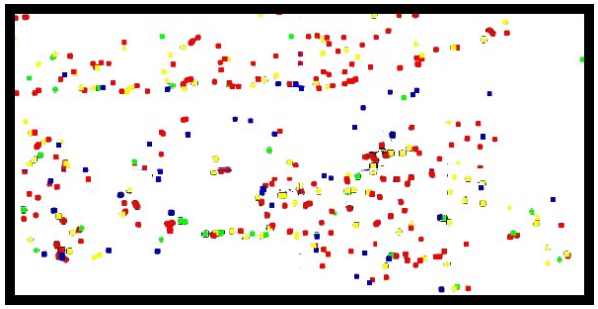
- **Performance (→onboard):**
  e.g. only 3DoF coarse tracking + gyro.

Future Work

- **Add feature**
  e.g. person following, gesture recognition, …
- **Obstacle Avoidance**
  e.g. using optical flow.
- …

Preview

Monocular SLAM without keypoints



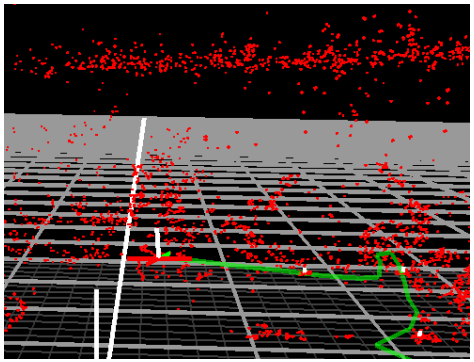


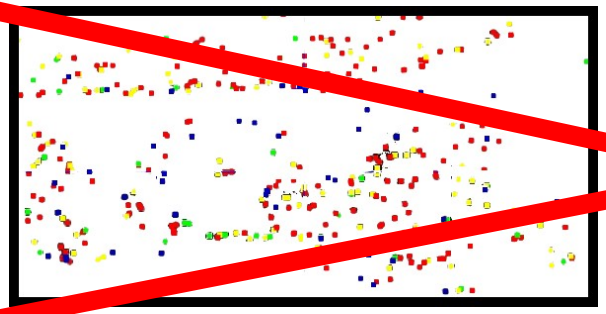
Image (pixels)

Features (e.g. point-positions)

Mapping, Tracking

Monocular SLAM without keypoints

Image
(pixels)



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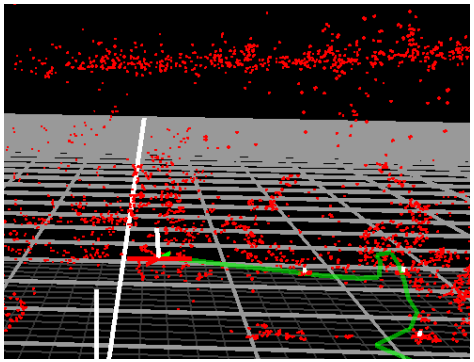
(e.g. point-positions)



Mapping,
Tracking

Preview

Thanks!

Questions?