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A Proof-Of-Concept Demonstration of Visual Teach and Repeat on a Quadrocopter Using an Altitude Sensor and a Monocular Camera

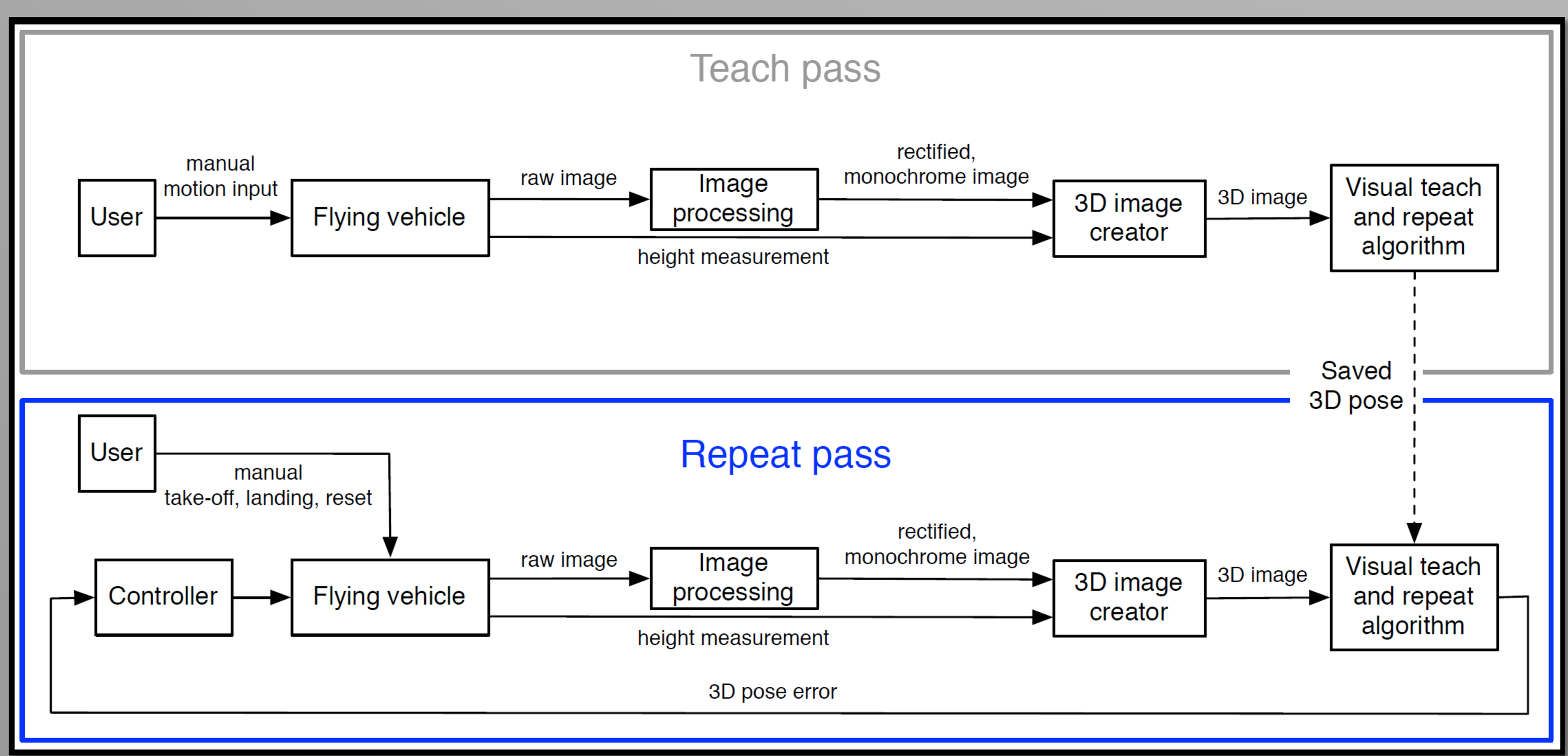
Summary

- **Contribution:**
  - Vision-based navigation with a micro aerial vehicle (MAV)
  - Teach-and-repeat strategy to autonomously repeat a manually taught route
- **Novelty:**
  - 3D vision sensor in [1] replaced by a monocular downward-looking camera combined with an altitude sensor
- **Experiments:**
  - Reliable, fully autonomous flight of an 8-m-long, straight and level route
  - Successful repetition of a 16-m-long route presented in a short video: www.tiny.cc/VTRflight

Visual Teach and Repeat (VT&R) with the AR.Drone 2.0

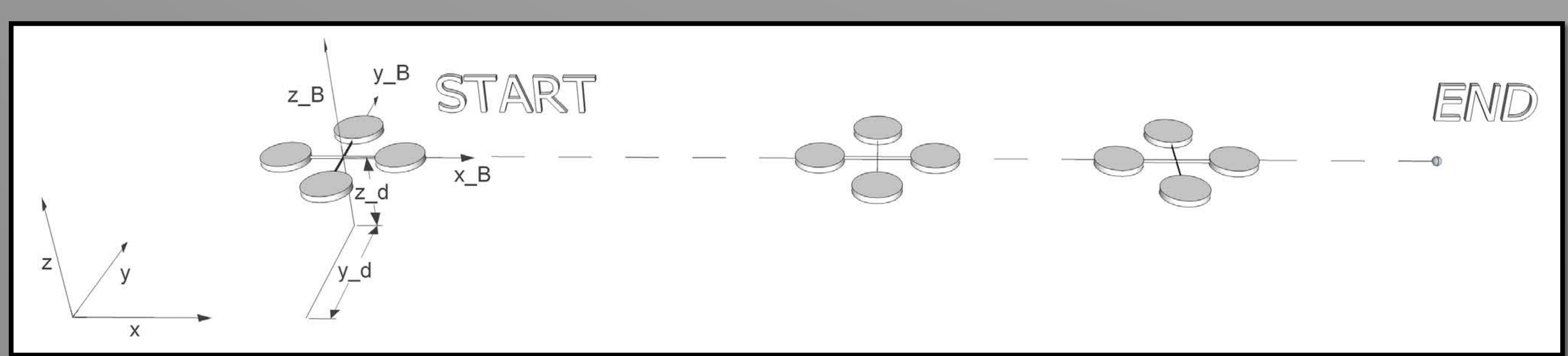
- **Approach:**
  - Building a manifold map composed of overlapping submaps in 'teach' phase
  - Using the created map to autonomously fly along the taught route in 'repeat' phase

- **Teach pass:**
  - Mounting the AR.Drone 2.0 to a cart and driving it along a desired route
  - Creating a new reference system in fixed intervals by extracting the interest points of the current image and storing their 3D positions together with the transformation between the current and the last reference system
- **Repeat pass:**
  - Using the map from the teach pass for localization and autonomous repeat
  - Comparing interest points of the live image with the stored interest points (map), calculating a 3D pose error used by the path-following controller



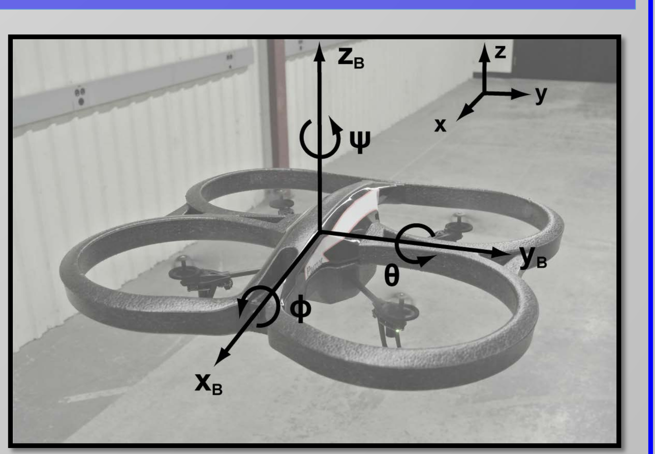
Assumptions

- Small pitch and roll angle
- Constant height during flight
- Flat ground
- Straight path



Control

- **Linear model of dynamics** (small-angle assumption):



$$\ddot{x}(t) = g\theta(t)$$
$$\ddot{y}(t) = -g\phi(t)$$
$$\dot{\psi}(t) = \omega(t)$$

- **Desired path** (straight and level):

$$x_d(t), \quad y_d(t) = y_d, \quad z_d(t) = z_d, \quad \psi_d(t) = 0$$

→ Autonomous repeat at predefined, constant velocity v_d

- **Assumption** (fast quadrocopter dynamics):

$$\theta(t) = \theta_{cmd}(t), \quad \phi(t) = \phi_{cmd}(t), \quad \omega(t) = \omega_{cmd}(t)$$

- **Inputs:**
  - pitch angle $\theta_{cmd}(t)$, roll angle $\phi_{cmd}(t)$, yaw rate $\omega_{cmd}(t)$
- **Outputs:**
  - linear velocity, $v(t)$, from on-board sensors
  - lateral error, $\epsilon_L(t) = y(t) - y_d$, from VT&R
  - heading error, $\epsilon_H(t) = \psi(t) - \psi_d$, from VT&R
- **Decoupled feedback controllers** (for pitch, roll and yaw):
  - Tuning parameters: $T_\theta, T_\phi, \zeta_\phi, T_\omega > 0$

$$\omega_{cmd}(t) = -\frac{1}{T_\omega}\epsilon_H(t)$$
$$\theta_{cmd}(t) = \frac{1}{gT_\theta}(v_d - v(t))$$
$$\phi_{cmd} = \frac{1}{g}\left[2\zeta_\phi\left(\frac{2\pi}{T_\phi}\right)\dot{\epsilon}_L(t) + \left(\frac{2\pi}{T_\phi}\right)^2\epsilon_L(t)\right]$$

Experimental Results

- Tests along an 8-m-long, straight and level route:
  - *Experiment 1 'Nominal':* proof of localization, perfect repetition on cart, 10x
  - *Experiment 2 'Off-nominal':* proof of localization, repetition with lateral offset of 0.2m, 5x
  - *Experiment 3 'Flying':* proof of autonomous flight (localization and controller), 10x

Repeat	Mean [m]	Std. dev. [m]
Nominal	-0.0041	0.0186
Off-nominal	-0.1908	0.0266
Flying	-0.0197	0.1031

(a) Lateral error

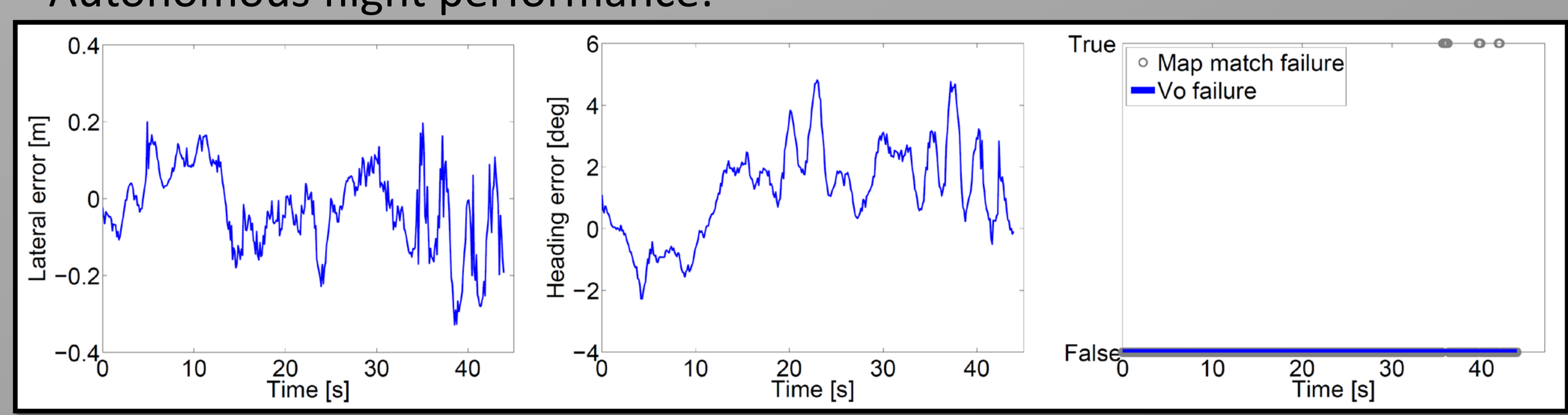
Repeat	Mean [deg]	Std. dev. [deg]
Nominal	0.8660	0.4903
Off-nominal	0.3151	0.5618
Flying	0.9944	1.6901

(b) Heading error

Repeat	VO [%]	Map match [%]
Nominal	0	1.6882
Off-nominal	0.1325	1.3100
Flying	0	20.8692

(c) Localization failure

- Autonomous flight performance:

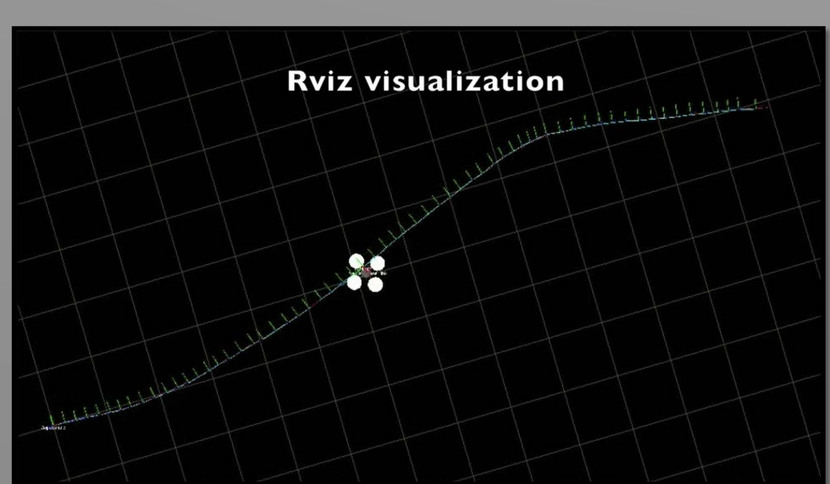


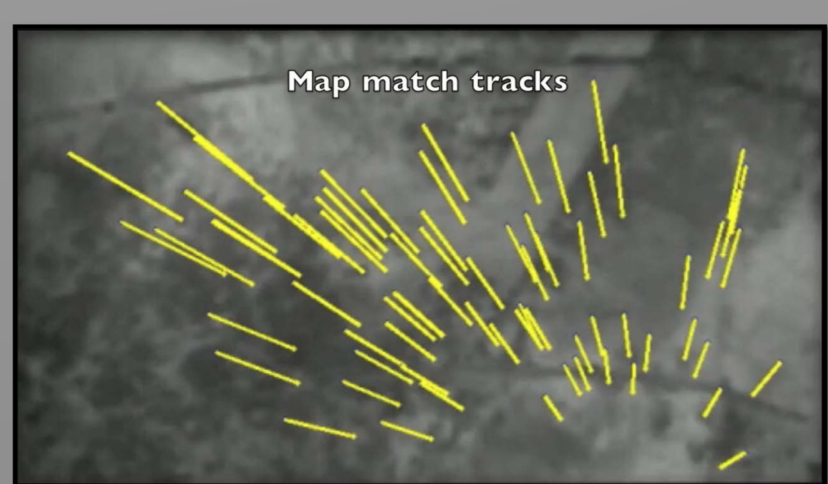
Conclusion

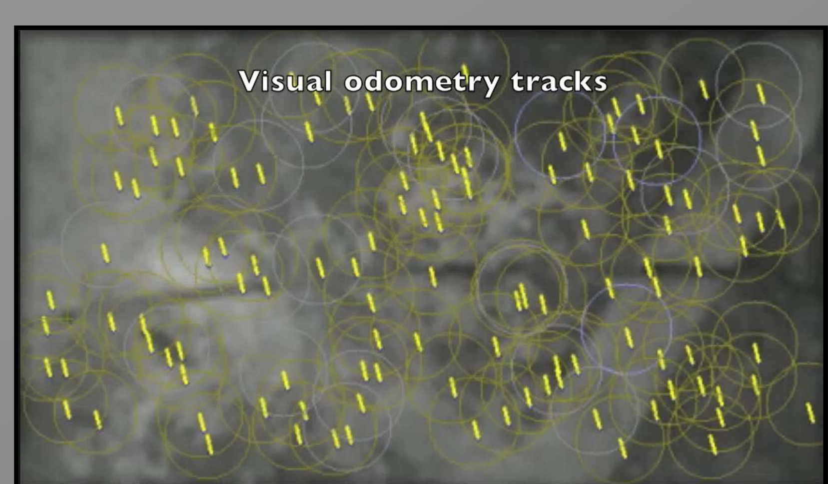
- Successful autonomous path-following along a previously taught route (straight and level) based on a monocular camera and an altitude sensor

Reference

[1] C. McManus, P. Furgale, B. Stenning, and T. Barfoot, "Visual teach and repeat using appearance-based lidar," in Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), 2012, pp. 389–396.







Paper: www.tiny.cc/VTRflightPaper, Video: www.tiny.cc/VTRflight, Prof. Schoellig: www.schoellig.name, Prof. Barfoot: www.asrl.utias.utoronto.ca, UTIAS: www.utias.utoronto.ca