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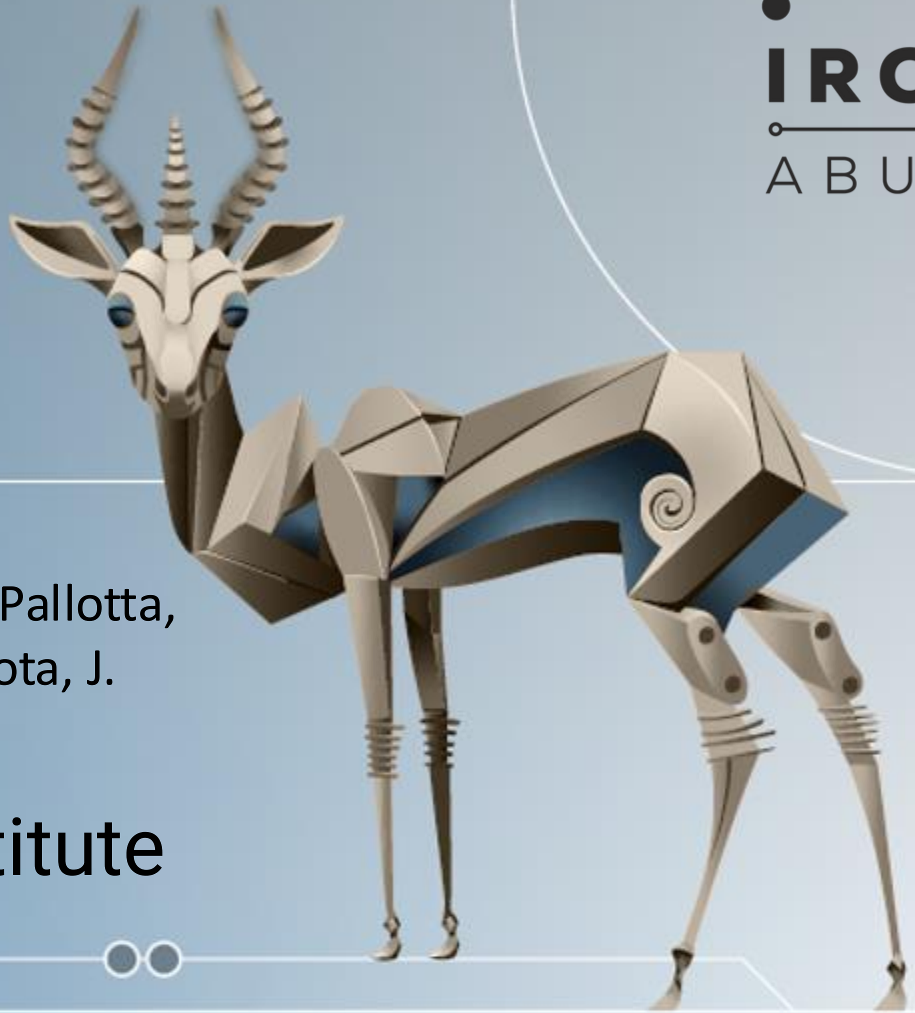
Race Against the Machine

A Fully-annotated, Open-design Dataset of Autonomous and Piloted High-speed Flight



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A Fully-annotated, Open-design Dataset of Autonomous and Piloted High-speed Flight

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Drone racing

A competitive sport where pilots control high-speed drones through challenging tracks, emphasizing agility, precision, and real-time navigation.

Pilots are equipped with a controller and goggles that allow them to have a FPV perspective

Drone Racing in research

Autonomous drone racing is a challenging field that effectively benchmarks drone technology

- High speed navigation
- Precise control and quick decision-making
- High stability during aggressive maneuvers.
- Complex real-time actions
- Accurate visual-inertial odometry and optimized aerodynamics
- Limited computational resources management

Why a New Drone Racing Dataset?

While there are existing datasets, they each have limitations that prevent them from being fully suitable for autonomous drone racing, or they focus only on specific aspects of the challenge

- Low speed trajectories
- Low frequency data sampling
- Lack of comprehensive annotations
- Limited real-world data
- Absence of dual flight modes
- Narrow focus, lacking holistic resources

Comparison with existing work

TABLE I: Comparison of multi-rotor and drone racing datasets for visual-inertial odometry, scene understanding, and control

Ref.	Time & Distance	Data Coll.	Conditions: Scene	Conditions: Lighting	Gates: Pose	Gates: Labels	Top Speed	Vision/Camera Specifications: Resolution/Freq.	Color	FoV	Stereo	Event	Pose/Inertial Data: IMU	MoCap	Control Inputs: CTBR	Motor	Battery Voltage	Data Formats
Ours	~25' ~8km	Real	Indoor	3 Levels Labeled	✓	✓†	9.5m/s$^{\diamond}$ 21.8m/s¶	640x480@120Hz	RGB	155°	✗	✗	@500Hz	@275Hz	@100Hz	@100Hz	@50Hz	rosbag, CSV, JPEG
[2]	~22' ~10km	Real	Indoor; Outdoor	Multiple, Unlabel.	✗	✗	12.8m/s$^{\diamond}$ 23.4m/s$^{\diamond}$	346x260@50Hz 640x480@30Hz*	Grayscale Grayscale	120° 186°	✓	✓	@500Hz @1000Hz	@20Hz§	✗	✗	✗	rosbag, TXT, PNG
[5]	n/a‡	Real	Indoor, 1 Gate	Multiple, Unlabel.	✗	✓$^{\|\|}$	n/a	1296x864	RGB	n/a	✗	✗	✗	✗	✗	✗	✗	JSON, JPEG
[6]	~10h ~100km	Real + Synth.	Indoor, 5 Scenes	Multiple, Unlabel.	✗	✗	7m/s	1024x768@120Hz†† 1024x768@360Hz††	Grayscale RGB	60°	✓	✗	@100Hz	@360Hz	✗	@190Hz	✗	rosbag, CSV, MP4, PNG Depth
[7]	~22' ~1km	Real	Indoor, 2 Scenes	Multiple, Unlabel.	✗	✗	2.3m/s	752x480@20Hz	Grayscale	115°	✓	✗	@200Hz	@20Hz§ @100Hz	✗	✗	✗	CSV, PLY, PNG
[8]	~10' ~3km	Real	Outdoor; 1 Scene	Multiple, Unlabel.	✗	✗	17.5m/s	960x800@40Hz	Grayscale	n/a	✓	✗	@200Hz	✗	✗	✗	✗	rosbag
[9]	~300' ~100km	Synth.	Indoor, 2 Scenes	Multiple, Unlabel.	✓	✓¶¶	13.8m/s	800x600@60Hz	RGB	120°	✗	✗	✗	@500Hz**	@500Hz	✗	✗	CSV, MP4
[10]	~75'	Real	n/a	✗	✗	✗	18m/s	✗	✗	✗	✗	✗	@1000Hz	@400Hz	✗	@1000Hz	@400Hz	CSV

†Bounding boxes, top-bottom left-rigth corners. $^{\diamond}$Piloted. ¶Autonomous. *Stereo. §Leica laser tracker. ‡9300 frames. $^{\|\|}$Internal corners. ††Synthetic camera images. ¶¶Area of interest of the gaze. **Simulated.

Our Dataset in a Nutshell

- Fast (>20m/s) and aggressive quadrotor flights
- Autonomous and human-piloted flights
- Multiple trajectories
- Visual, inertial, and motion capture data
  - high-resolution
  - high-frequency
- Drone racing gates
  - bounding boxes
  - individual corner labels
- Control inputs and battery voltages

Design Overview

Structure

- 5-inch carbon-fiber frame
- 215 mm of propeller-to-propeller diagonal distance
- 870g of weight

Performance capabilities

- Speeds up to 179 km/h
- High linear acceleration (69.85 m/s^2)
- High angular velocity (20.01 rad/s)

Flight modes

- Suitable for both autonomous and human piloted flights

Autonomous module

- NVIDIA Orin NX (hosted on an A203v2 carrier board with SSD and wireless card)

Sensors

- MPU6000 IMU embedded in the flight controller
- Arducam RGB camera.

Other features

- Open-source design
- Made of Commercial off-the-shelf (COTS) components

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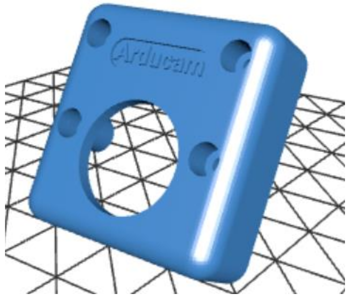
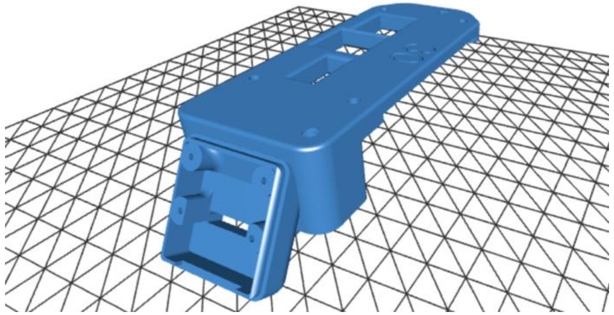
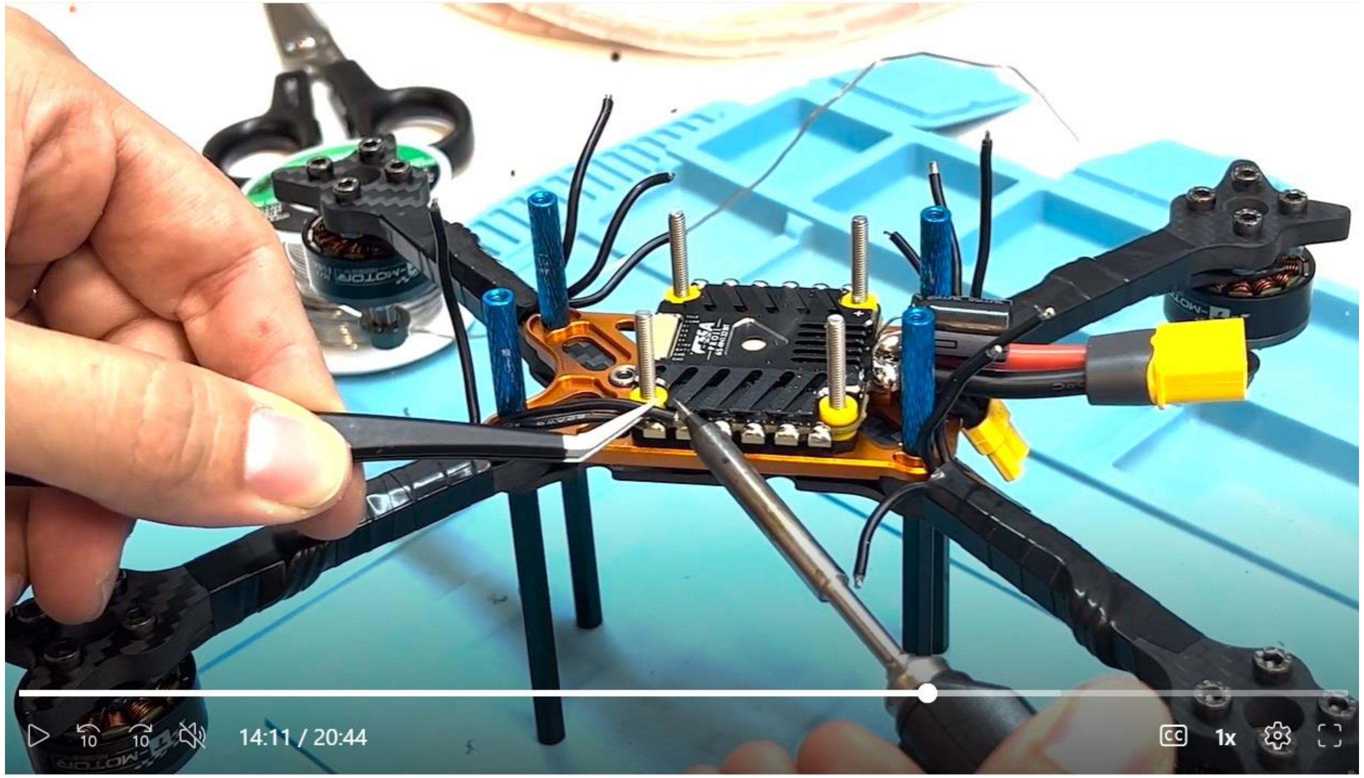
Reproducibility





Release of:

- Design of the drone used to collect the data
  - Bill of Material
  - 3D models
  - Building tutorial
- Reference controller code used for autonomous flight
- Betaflight parameters



Data collection

Motion capture system

Providing the ground truth for the drone (275 Hz) and the gate poses

Arducam IMX219 Bayer camera

Capturing 640x480 px images (120Hz)

Flight controller

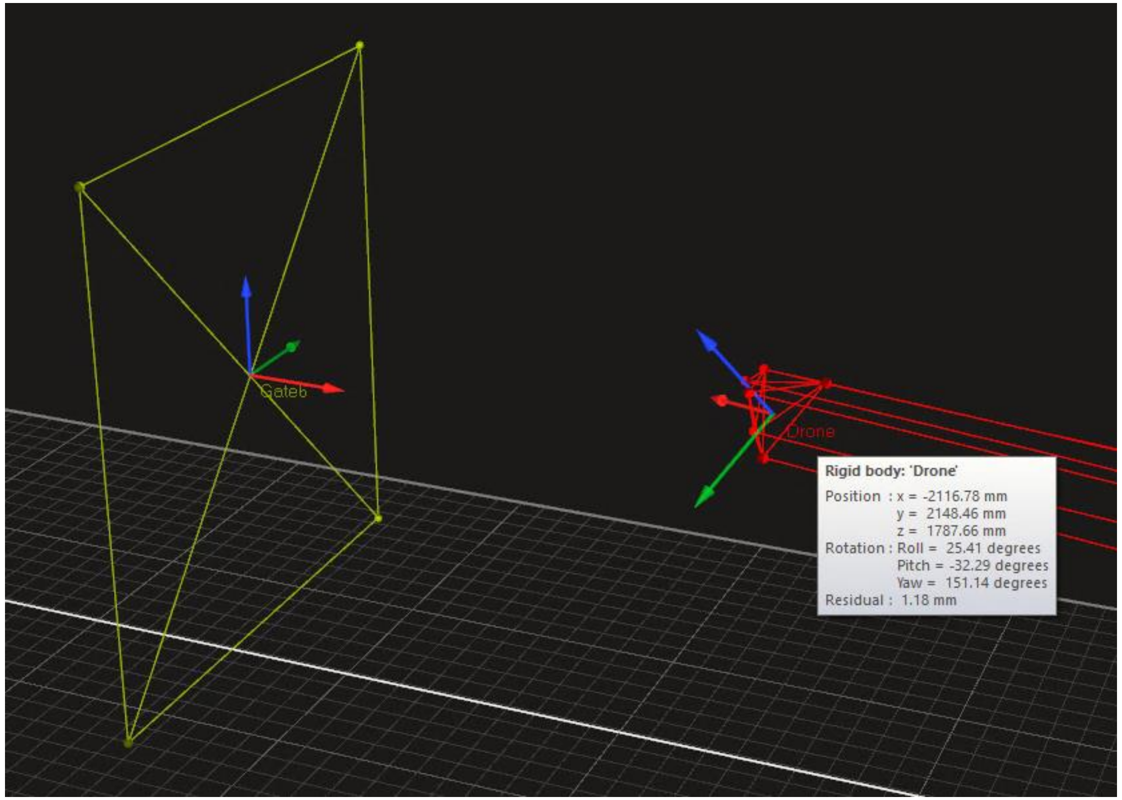
Providing IMU data (500Hz), battery voltage (50Hz), motor outputs (100Hz) and remote control inputs (100Hz)

Companion computer

Providing autonomous control references (100Hz 2D tracks, 500Hz 3D tracks) and control inputs (275Hz 2D tracks/ 160Hz 3D tracks)

NTP server

Used to synchronize the companion computer with the motion capture system



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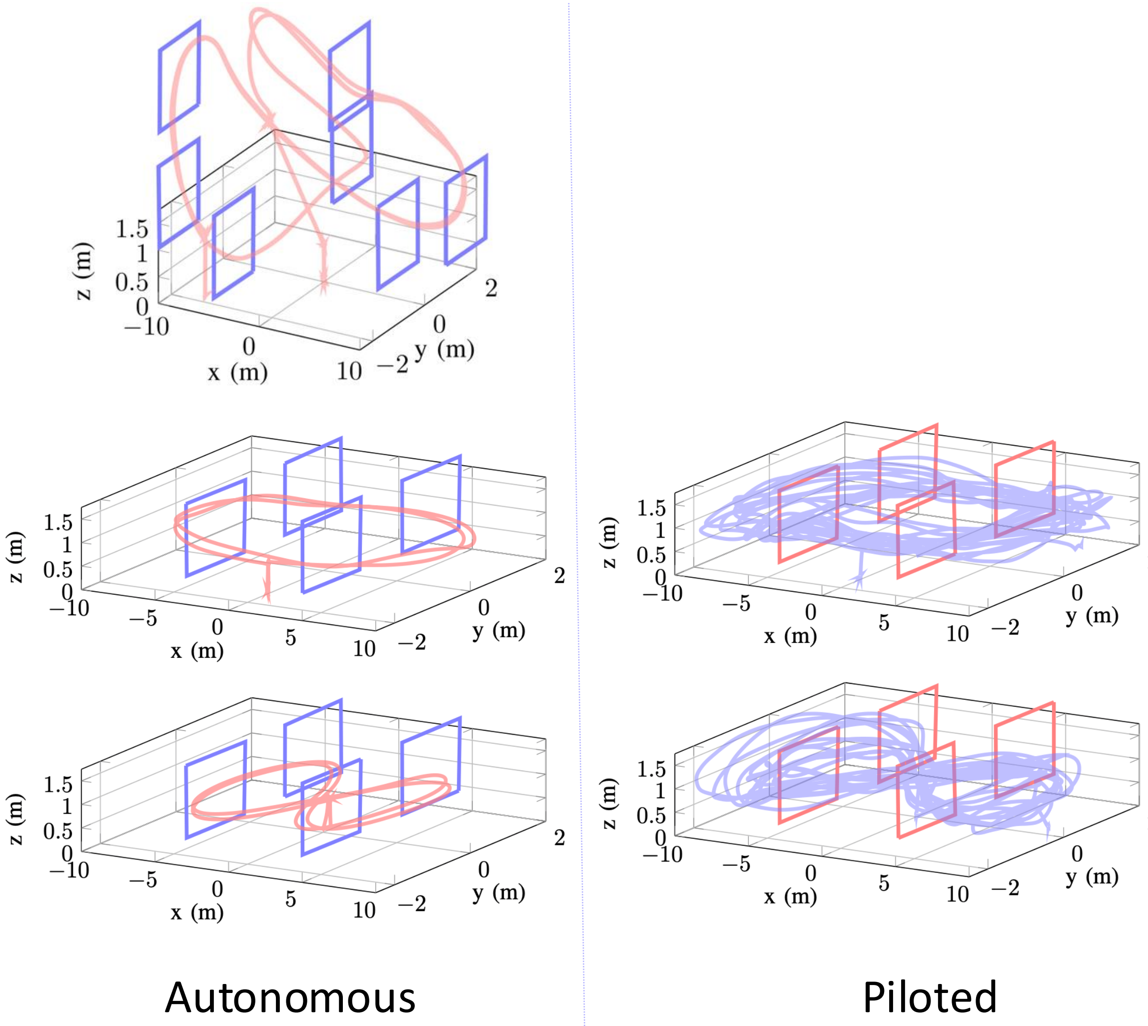
Recorded Flights

TABLE III: Summary of the flights recorded in the dataset

Control	Shape	Top Speed	Time	Distance
Autonomous	Ellipse†	**21.83 m/s**	149.08 s	455.27 m
	Lemniscate†	10.22 m/s	155.08 s	359.63 m
	Race Track‡	21.39 m/s	278.05 s	1161.51 m
Piloted	Ellipse§	9.50 m/s	575.38 s	2586.3 m
	Lemniscate§	8.93 m/s	**593.63 s**	**2593.47 m**

†Flown twice in 6 flights (3 brightness × 2 camera settings). ‡Flown three times in 6 flights (3 brightness × 2 camera settings). §Flown as many times as possible in 6 flights (3 brightness × 2 camera settings).



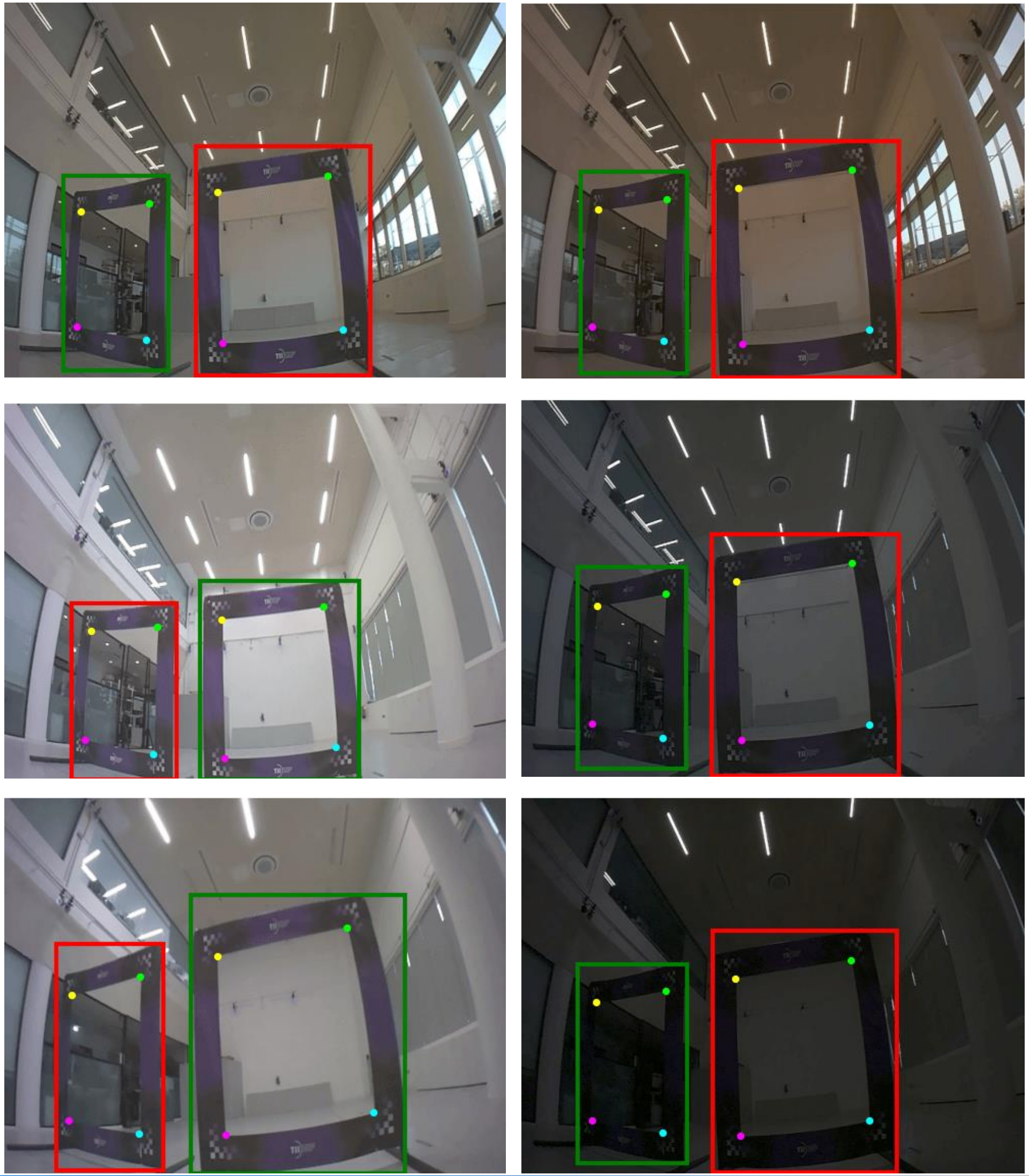


Image settings

Environment brightness

- Full light
- Artificial light
- Low light

Camera settings

- Auto exposure
  - Automatically adjusted exposure time and gains
  - Results in brighter images
  - Higher motion blur
- Fixed exposure
  - Exposure time: 2.5 ms
  - Analog gain: 2
  - Digital gain: 1
  - Results in darker images
  - Limits motion blur

Post processing

Data trimming

- Any records that occur before take-off and after landing have been removed

Data alignment

- A script is used to interpolate the data and ensure that all measurements are synchronized based on timestamps. Linear interpolation is applied to most fields, while spherical linear interpolation is used for rotation matrices.

Creation of comprehensive CSVs

- Camera-aligned CSVs
  - align all the other data points with the timestamps from the camera frames
- Uniform Sampling CSVs
  - sample data at a uniform frequency (500Hz) between the first and last camera timestamps.

Metadata

- Each flight folder includes a YAML metadata file summarizing important information such as camera settings, light conditions, type of track, total flight time, and distance traveled

TABLE IV: Data available in the precompiled `cam_ts_sync.csv` and `500hz_freq_sync.csv` (Sec. V-A)

Column Number and Quantity Name	Unit	Data Type
0. `elapsed_time`	s	float
1. `timestamp`	μs	int
2. `img_filename`	n/a	string
3. `accel_[x|y|z]`	m/s^2	float
6. `gyro_[x|y|z]`	rad/s	float
9. `thrust[0-3]`	1	float $\in [0, 1]$
13. `channels_[roll|pitch|thrust|yaw]`	1	int $\in [1000, 2000]$
17. `aux[1-4]`	1	int $\in [1000, 2000]$
21. `vbat`	V	float
22. `drone_[x|y|z]`	m	float
25. `drone_[roll|pitch|yaw]`	rad	float
28. `drone_velocity_linear_[x|y|z]`	m/s^2	float
31. `drone_velocity_angular_[x|y|z]`	rad/s	float
34. `drone_residual`	m	float
35. `drone_rot[[0-8]]`	1	float
44. `gate[1-4]_int_[x|y|z]`	m	float
56. `gate[1-4]_int_[roll|pitch|yaw]`	rad	float
68. `gate[1-4]_int_residual`	m	float
72. `gate[1-4]_int_rot[[0-8]]`	1	float
108. `gate[1-4]_marker[1-4]_[x|y|z]`	m	float

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Data Format

Raw data

- Rosbags
- Single CSVs

Interpolated data

- Camera-aligned
- Uniform-sampling

Images and labels

- JPEG
- TXT ($0\ c_x\ c_y\ w\ h\ tl_x\ tl_y\ tl_v\ tr_x\ tr_y\ tr_v\ br_x\ br_y\ br_v\ bl_x\ bl_y\ bl_v$)

```
https://github.com/tii-racing/drone-racing-dataset/data/
└ [autonomous|piloted]
  └ flight-[01-12][a|p]-[ellipse|lemniscate|trackRATM]/
    ├ csv_raw/
    │ ├ ros2bag_dump/
    │ │ ├ battery_flight-01a-ellipse.csv
    │ │ ├ channels_flight-01a-ellipse.csv
    │ │ ├ *ctbr_flight-01a-ellipse.csv
    │ │ ├ drone_state_flight-01a-ellipse.csv
    │ │ ├ imu_flight-01a-ellipse.csv
    │ │ ├ motors_thrust_flight-01a-ellipse.csv
    │ │ └ *reference_flight-01a-ellipse.csv
    │ ├ camera_flight-01a-ellipse.csv
    │ ├ gate_corners_flight-01a-ellipse.csv
    │ └ mocap_flight-01a-ellipse.csv
    ├ ros2bag_flight-01a-ellipse/
    │ ├ metadata.yaml
    │ └ ros2bag_flight-01a-ellipse.db3
    ├ camera_flight-01a-ellipse.zip
    ├ label_flight-01a-ellipse.zip
    ├ flight-01a-ellipse_500hz_freq_sync.csv
    ├ flight-01a-ellipse_cam_ts_sync.csv
    └ metadata_flight-01a-ellipse.yaml
```

* Only in the autonomous flight folders.

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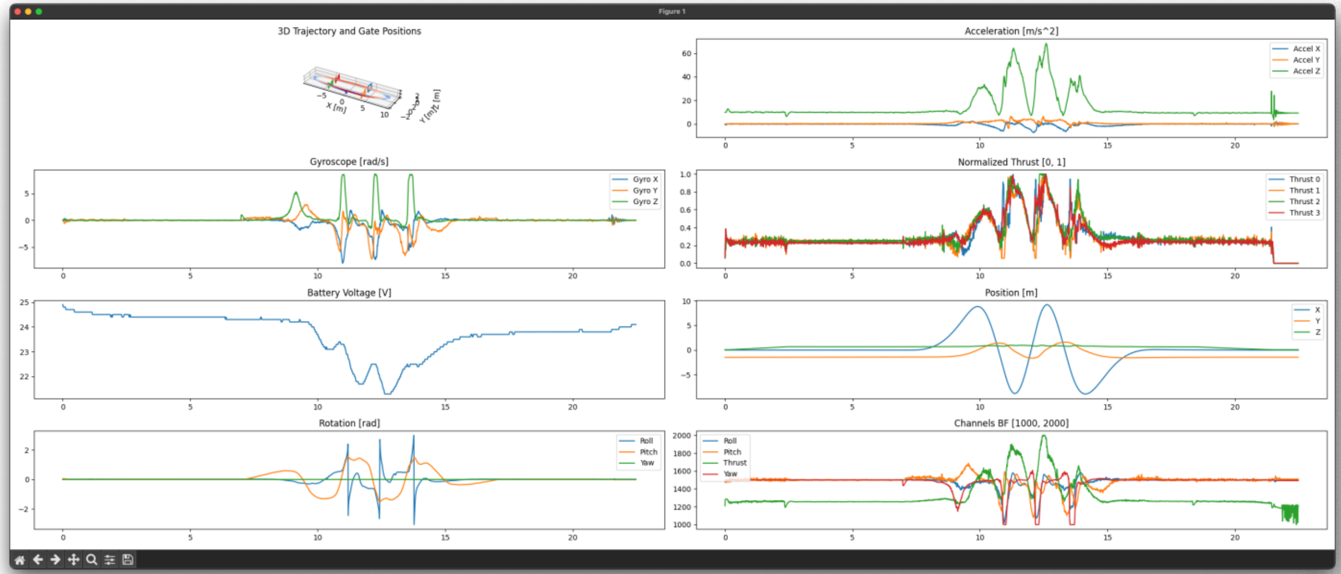
Supporting Scripts



Additional Resources:

- camera_calibration
  - calibration_results.json — Camera parameters in JSON format.
  - calibration_results.npz — Camera parameters in NumPy format.
  - drone_to_camera.json — Translation from the drone center to the camera
- scripts
  - camera_calibration.py — Script used to generate the files in `camera_calibration/`.
  - create_std_bag.py. — Script used to generate standard ROS2 bags
  - data_interpolation.py — Script used to generate the comprehensive CSV files interpolated at arbitrary frequencies.
  - reference_controller.py — PID controller used for the autonomous flights.

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RA-L Paper

Dataset

https://doi.org/10.1109/LRA.2024.3371288

https://github.com/tii-racing/drone-racing-dataset

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Thank you!

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