Quadrotor Flight Dataset

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September 2, 2017

1 Hardware

The AscTec[1] Pelican[2] is a light weight quadrotor. It is equipped with a real-time autopilot board coupled with an onboard computer using Intel Core i7 and 4GB of RAM.[3] The onboard computer runs Ubuntu[4] 14.04 OS and communicates with the autopilot board via a UART connection. The ROS[5] Indigo[6] software running a suitable ROS node[7] is used to collect the motor speeds and Inertial Measurement Unit (IMU) measurements. The vehicle is operated in an indoor environment by an expert pilot using a Futaba T7C remote control.

The vehicle position and inertial orientation are measured at 100 Hz using a Vicon motion capture system[8], equipped with 16 Vantage cameras[9]. The position and orientation of the vehicle are instantaneously read by the Vantage cameras, looking at the IR reflective markers mounted on the vehicle, and sent to the Vicon server through a LAN communication (Figure 1). To avoid any wireless latency and/or packet drops, the measurements are logged on the Vicon server computer using the Vicon Tracker software version 3.3 which runs in the Microsoft Windows 10[10] OS. The Vicon system is calibrated before each data collection session to account for changes in environmental variables, such as room temperature, camera body temperature, etc.. The data collection diagram is depicted in Figure 2.

2 Measurements

The logged measurements are listed in Table 1. The indices, I and B refer to the frame of measurement, I is inertial (Vicon system) and B is the quadrotor body. The index g highlights the fact that the measurement is done by the gyroscopic sensors. All of the listed quantities are measured at 100Hz rate. After cutting the landing parts, the dataset total flight time is approximately 3 hours and 50 minutes. The total number of samples per each element of each quantity is 1388410.

The indoor environment in which the quadrotor flight was captured is approximately a cube with 5 meters sides. The flights were executed in several days and with several batteries (of the same type). However, the batteries age was different. This may influence the amount of current that can be drawn when a full throttle command is issued to the quadrotor.

The ROS node provides two types of motor speed, one is the *commanded*, and the other is the *actual*. They correspond to the desired speed, given to the motor controller, and the actual speed, that the motor spins at. The actual motor speed is *estimated* by the AscTec autopilot board based on the amount of

[1] Ascending Technologies, is a part of Intel.
[2] http://www.asctec.de/en/uav-uas-drones-rpas-roav/asctec-pelican/
[3] The onboard computer is AscTec Mastermind Ascending Technologies
[4] http://www.ubuntu.com
[5] http://www.ros.org
[6] http://wiki.ros.org/indigo
[7] http://wiki.ros.org/asctec_mav_framework
[8] https://www.vicon.com/products/camera-systems
[9] https://www.vicon.com/products/camera-systems/vantage
[10] https://www.microsoft.com/en-ca/windows/

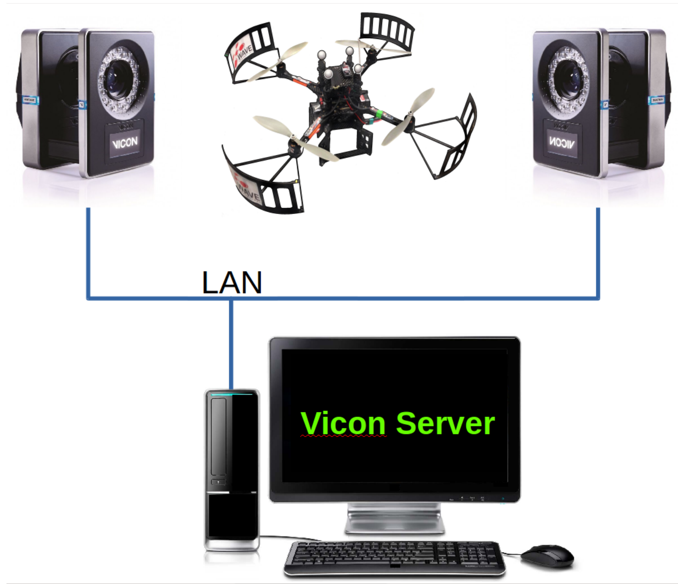

Figure 1: Vicon measrements of the quadrotor position and orientation.

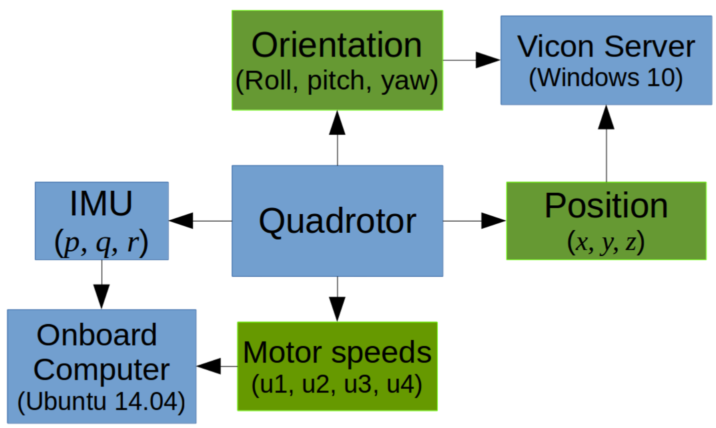

Figure 2: Communication block digram for the quadrotor dataset collection

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Quantity	Unit	Source	Logged in
Motor speeds $\boldsymbol{\omega}(k) = [\omega_1(k), \omega_2(k), \omega_3(k), \omega_4(k)]$	Integer values in [0, 218]	AscTec autopilot board	Mastermind
Inertial position $\mathbf{p}_I(k) = [x_I(k), y_I(k), z_I(k)]$	mm, $\pm$5mm accuracy	Vicon system	Vicon server
Inertial orientation, Euler angles $\boldsymbol{\eta}_I(k) = [\phi(k), \theta(k), \psi(k)]$	deg., $\pm$0.1deg. accuracy	Vicon system	Vicon server
Body rates $\dot{\boldsymbol{\eta}}_{B,g}(k) = [p_g(k), q_g(k), r_g(k)]$	deg., unknown accuracy	Pelican IMU	Mastermind

Table 1: Pelican measurements.

current the motors draw. Both the commanded and actual speeds are available as integer values. It is possible to experimentally devise a mapping to RPM, however, using NNs it is not necessary.

A smoothing filter is applied to all of the measurements with a window size of 5. The filter is a local-regression which approximates the signal at each sample point by a 2nd degree polynomial. For the motor speeds, a robust version of this filter is applied that assigns lower weight to outliers in the regression to reduce the effect of current spikes in the motor control units.[11]

Because the position and heading can grow unbounded, it is preferred to learn velocities and body rates. The velocity vector, $\dot{\mathbf{p}}_I(k) = [\dot{x}_I(k), \dot{y}_I(k), \dot{z}_I(k)]$ is obtained by taking the numerical derivative of the position vector, $\mathbf{p}_I(k)$. To obtain body rates, $\dot{\boldsymbol{\eta}}_B(k) = [p(k), q(k), r(k)]$, first the Euler rates, $\dot{\boldsymbol{\eta}}_I(k) = [\dot{\phi}(k), \dot{\theta}(k), \dot{\psi}(k)]$ are obtained by taking the numerical derivative of the Euler readings, $\boldsymbol{\eta}_I(k)$. Then the Euler rates are transferred to the body frame using the following equations,

$$\dot{\boldsymbol{\eta}}_B(k) = \mathbf{M}(\phi(k), \theta(k), \psi(k))\dot{\boldsymbol{\eta}}_I(k) \tag{1}$$

where the matrix-valued function $\mathbf{M}(.)$ is given by:

$$\mathbf{M}(\phi, \theta, \psi) = \begin{bmatrix} 1 & \sin(\phi)\tan(\theta) & \cos(\phi)\tan(\theta) \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi)\sec(\theta) & \cos(\phi)\sec(\theta) \end{bmatrix}. \tag{2}$$

Although IMU readings for the body rate is usually used in control applications, they are quite noisy. Additionally, the IMU yaw readings are known to have drifts over time. Therefore, it is preferred to use the converted Euler readings instead. However, they are employed as a medium to adjust the time delays as described next.

3 Time synchronization

Although the Vicon system is one of the best commercially available Indoor Positioning Systems, there are some limitations. For instance, the Vicon server operating system is Windows 10 which is not a real time OS. In the current configuration, there are three sources of delay; the onboard computer OS, the Vicon server OS and the ROS software. Perfectly synchronizing time stamps between various sources of measurement requires levels of sophisticated hardware and software solutions. However, in the current configuration it is possible to approximately adjust the time delays.

The IMU measurements and motor speeds are received by the ROS node at the same time. Thus, they share time stamp. Aligning the IMU body rates with the Vicon converted body rates should fairly compensate for any time delays. The alignment is simply done by a cross-correlation between the two signals. Note that both IMU and Vicon system provide measurements at the same frequency (100 Hz).

In conclusion, the quantities included in the quadrotor dataset are

- actual motor speed, $\boldsymbol{\omega}(k) = [\omega_1(k), \omega_2(k), \omega_3(k), \omega_4(k)]$,
- velocity vector in inertial frame, $\boldsymbol{\nu}(k) = [\dot{x}_I(k), \dot{y}_I(k), \dot{z}_I(k)]$,
- body rates, $\dot{\boldsymbol{\eta}}_B(k) = [p(k), q(k), r(k)]$.

4 Distributions

The dataset consists of various flight regimes; hover, close to ground, light, moderate and aggressive manoeuvres in all directions, etc. Figures 3, 4 and 5 illustrate the distribution of the signals, which noticeably are fairly symmetric.

[11] Refer to the MATLAB (The MathWorks Inc.) documentation for the smooth function.

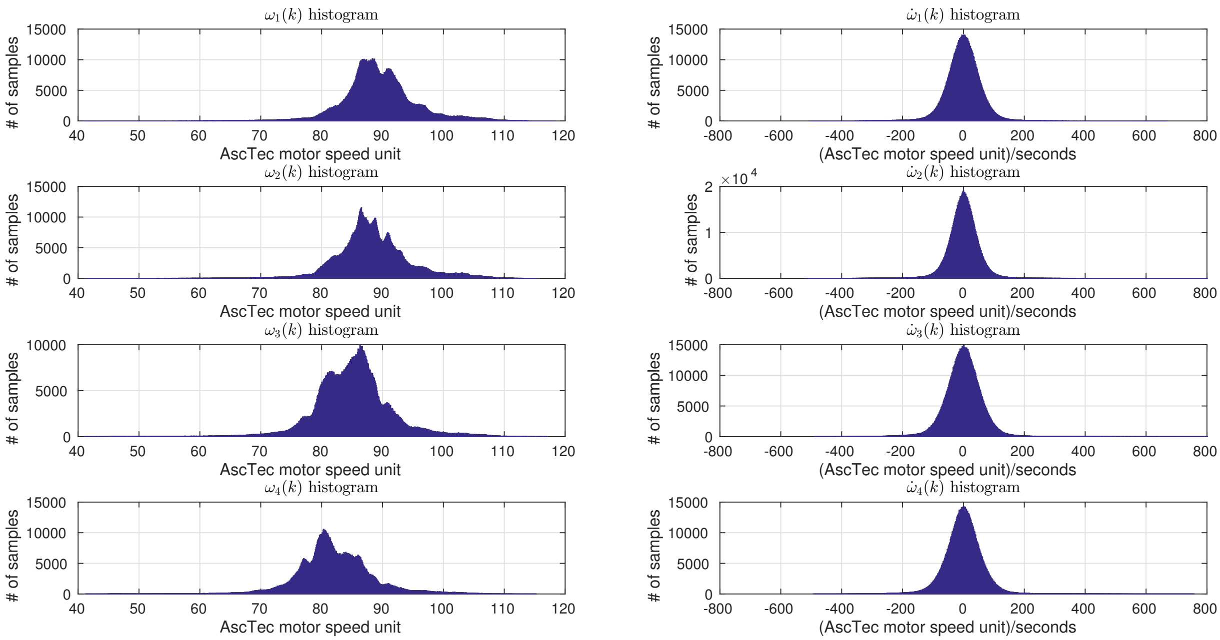

Figure 3: Distribution of the quadrotor motor speeds and their rate of change.

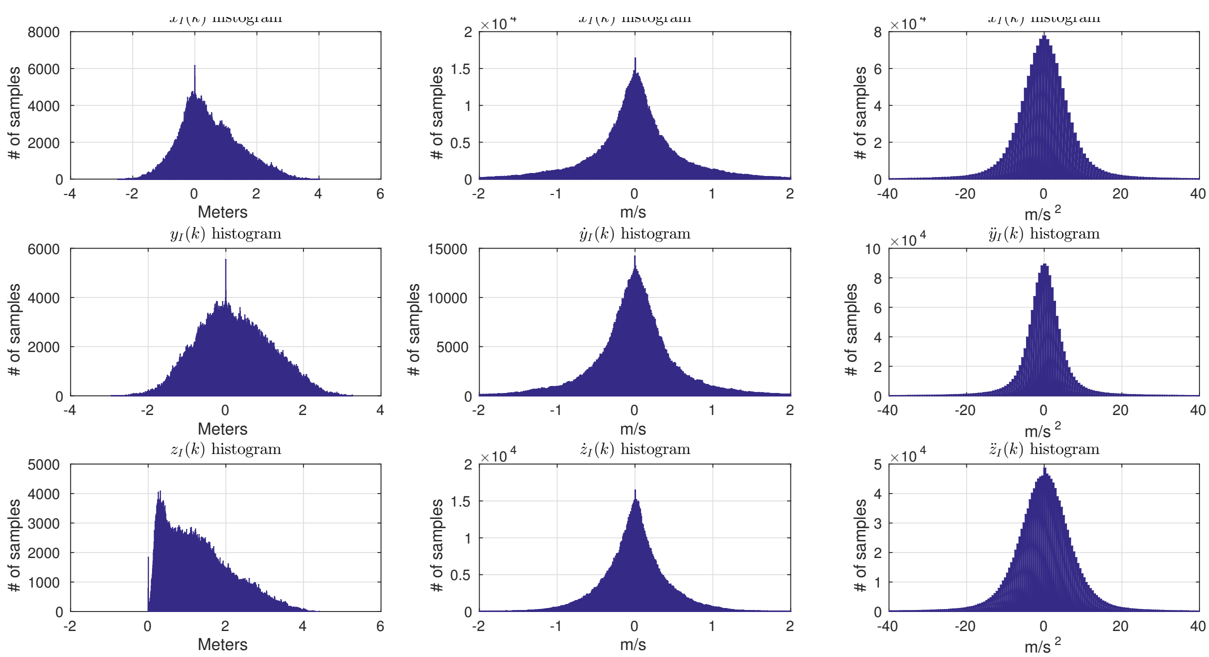

Figure 4: Distribution of the quadrotor position, velocity and acceleration.

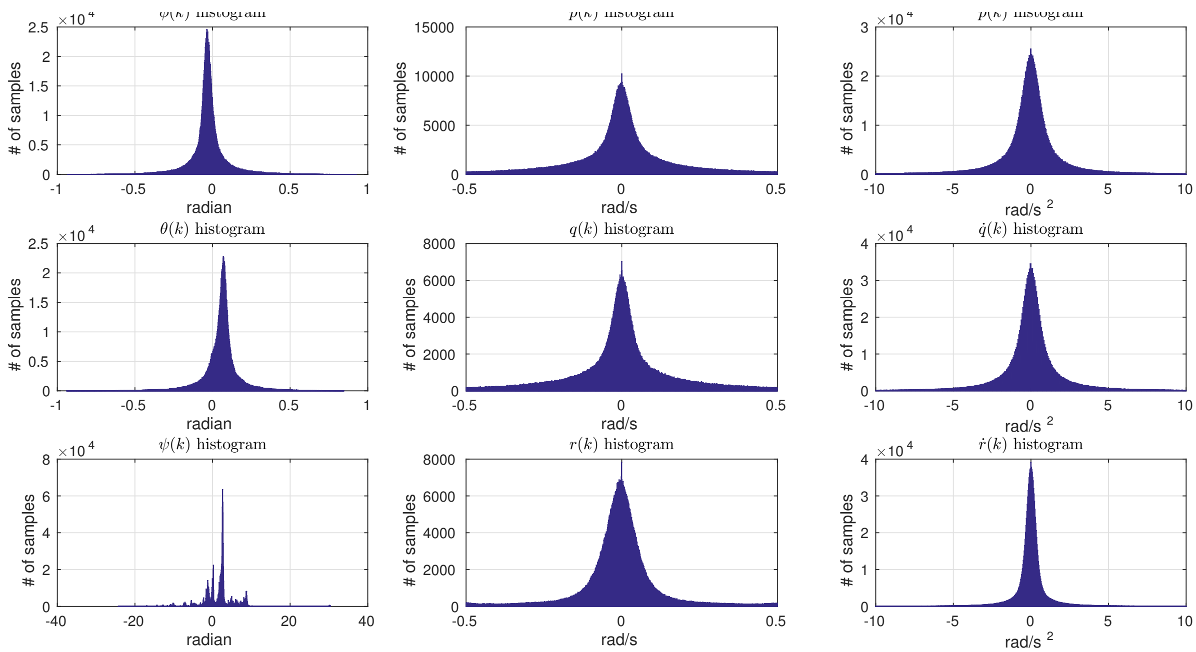

Figure 5: Distribution of the quadrotor orientation, in the inertial frame, body rates and body rotational accelerations, in the body frame.