Autonomous “Figure-8” Flights of a Quadcopter: Experimental Datasets

Srikanth Gururajan 1,* and Ye Bai 2

1 Aerospace Engineering, Parks College of Engineering, Aviation and Technology, Saint Louis University, St. Louis, MO 63103, USA
2 Decentralized Finance Labs Inc, Palo Alto, CA 94301, USA; baiye0225@outlook.com
* Correspondence: srikanth.gururajan@slu.edu

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Abstract: This article describes the data acquired from multiple flights of a custom-built quadcopter. The Quadcopter was programmed to fly a pre-defined “Figure-8” flight path, at a constant altitude. The data set includes flights with a varying number of waypoints (10 and 15 waypoints in each lobe of the “Figure-8”) and at two different velocities (1.5 and 2.5 m/s). The data also contains information on the output of the flight controller in terms of the Pulse Width Modulation (PWM) signals to each of the four Electronic Speed Controllers (ESC) driving the motors, the recorded outputs of the Inertial Measurement Unit (linear accelerations $a_x$, $a_y$, $a_z$ and angular velocities $p$, $q$, $r$), GPS data (Latitude, Longitude, altitude, Horizontal Dilution of Precision (HDOP) and Vertical Dilution of Precision (VDOP). The data are included as Supplemental Material.


Dataset License: CC-BY-SA-NC-ND

Keywords: quadcopter; flight data; pixhawk

1. Summary

Unmanned Aerial Systems (UAS) or drones have rapidly evolved and the number and type of their applications have proliferated. In particular, these are promising platforms for performing repetitive and often dangerous tasks, thanks to their versatility, low cost, and minimal risk. The recent release of the Federal Aviation Administration’s rules for commercial usage of drones (Small Unmanned Aircraft Regulations Part 107) [1] underscores the broad desire to use drone platforms in a variety of commercial applications including structural surveying [2], search and rescue [3,4], disaster recovery [5] and many others; while this is true, it also leads to the question of reliability and performance of various flight controllers that are integral to their flight capabilities. At the AirCRAFT Laboratory in Parks College of Engineering, Aviation and Technology at Saint Louis University, we have conducted autonomous experimental flight tests of a custom-built quadcopter multi-rotor UAV platform, flying a “Figure-8” pattern. The experiments were performed with a different number of waypoints (10 and 15 per lobe) and under different velocities (1.5 m/s and 2.5 m/s). The quadcopter featured a Commodity-Off-The-Shelf (COTS) Pixhawk flight controller, which also served as the data acquisition and storage device.

The experiments were performed as part of an unfunded research project and led to a Master’s thesis for the second author [6]. We intend to leverage this dataset to evaluate the performance of the flight controller in terms of overall control effort as well as waypoint capture under different flight conditions, including GPS coverage, number of waypoints, and flight velocity. Additionally, we expect that the availability of this data set to the research community will be beneficial in the following ways:
- Facilitate performance evaluation of a widely used Commodity-Off-The-Shelf (COTS) flight controller, Pixhawk 1 [6], under different conditions (GPS coverage, flight velocities, waypoints etc.)
- This data can be used for comparing the performance of different flight controllers on multirotor drones and to design/simulate/evaluate flight control algorithms.
- This data could be used to evaluate the workload on COTS flight controllers, as well as in the design and implementation of resource-aware flight control algorithms.

2. Data Description

This article describes data from autonomous flights of a custom-designed and fabricated Quadcopter, conducted at the AirCRAFT Laboratory, Parks College of Engineering, Aviation and Technology, Saint Louis University, St. Louis, MO, USA. The Quadcopter was programmed to fly a pre-defined “Figure-8” flight path, at a constant altitude, as illustrated in Figures 1 and 2.

![“Figure – 8” path image](image1)

Figure 1. Side profile of autonomous flight path.

![“Figure-8” flight path, 10 waypoints image](image2)

Figure 2. A sample “Figure-8” flight path.

The Data Files included with this article describe flights with a varying number of waypoints (10 and 15 waypoints in each lobe of the “Figure-8”) and at two different velocities (1.5 and 2.5 m/s). Table 1 lists the flight variables available in the datasets.
### Table 1. Description of data channels in experimental data sets.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Descriptor (Variable Label)</th>
<th>Channels</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHR2</td>
<td>AHR2_label</td>
<td>Roll, Pitch, Yaw, Alt, Lat, Lng</td>
<td></td>
</tr>
<tr>
<td>BARO</td>
<td>BARO_label</td>
<td>Alt, Press, Temp, CRt, SMS, Offset</td>
<td></td>
</tr>
<tr>
<td>CMD</td>
<td>CMD_label</td>
<td>CTot, CNum, Cl, Prm1, Prm2, Prm3, Prm4, Lat, Lng, Alt</td>
<td></td>
</tr>
<tr>
<td>CTUN</td>
<td>CTUN_label</td>
<td>ThI, ABst, ThH, DAlt, Alt, BALt, DSAlt, SAlt, TAlt, DCRt, CRt</td>
<td>Control, Throttle, and altitude information</td>
</tr>
<tr>
<td>CURR</td>
<td>CURR_label</td>
<td>Volt, Curr, CurrTot</td>
<td></td>
</tr>
<tr>
<td>GPA</td>
<td>GPA_label</td>
<td>VDop, HAcc, VAcc, SAcc, VV, SMS</td>
<td>This contains the Vertical Dilution of Precision (VDOP) parameter</td>
</tr>
<tr>
<td>GPS</td>
<td>GPS_label</td>
<td>Status, GMS, GWk, NSats, HDop, Lat, Lng, Alt, Spd, GCr, VZ, U</td>
<td>This contains the Horizontal Dilution of Precision (HDOP) parameter</td>
</tr>
<tr>
<td>IMU, IMU2</td>
<td>IMU_label, IMU2_label</td>
<td>GyrX, GyrY, GyrZ, AccX, AccY, AccZ, ErrG, ErrA, Temp, GyHlt, AcHlt</td>
<td>Body axis angular rates ($p$, $q$, $r$) and accelerations ($a_x$, $a_y$, $a_z$)</td>
</tr>
<tr>
<td>MAG, MAG2</td>
<td>MAG_label, MAG2_label</td>
<td>MagX, MagY, MagZ, OfxX, OfyY, OfzZ, MOfxZ, MOfyY, MOfzZ, Health, S</td>
<td></td>
</tr>
<tr>
<td>NKF1- NKF9</td>
<td>NKF1_label–NKF9_label</td>
<td>Roll, Pitch, Yaw, VN, VE, VD, dPD, PN, PE, PD, GX, GY, GZ</td>
<td>More details can be found in [7]</td>
</tr>
<tr>
<td>PM</td>
<td>PM_label</td>
<td>NLon, NLoop, MaxT, PMT, I2CErr, INErr, LogDrop</td>
<td>Performance Monitoring</td>
</tr>
<tr>
<td>POS</td>
<td>POS_label</td>
<td>Lat, Lng, Alt, RelAlt</td>
<td>Position Log</td>
</tr>
<tr>
<td>RCIN</td>
<td>RCIN_label</td>
<td>RC Inputs, Channels 1–16</td>
<td>Channels 1–4 are the outputs of the flight controller, fed to the four speed controllers controlling the motors</td>
</tr>
<tr>
<td>RCOU</td>
<td>RCOU_label</td>
<td>Output of the flight controller</td>
<td></td>
</tr>
</tbody>
</table>

Additional channels of data exist in the data set. Interested researchers could refer to the Pixhawk reference [8] for more details.

### 3. Methods

As described earlier, this data set contains flight data from a series of experimental flight tests conducted using a custom-designed quadcopter at the AirCRAFT Laboratory [9], Parks College of Engineering, Aviation and Technology at Saint Louis University, St. Louis, MO, USA. The quadcopter and its physical dimensions are shown in Figures 3 and 4, respectively. It is approximately in the
350-mm class and features an additively manufactured central hub and carbon fiber arms. Additional details of the quadcopter frame are given in the following paragraph.

![Custom-built quadcopter](image1)

**Figure 3.** The custom-built quadcopter used in the experiments.

![Physical dimensions](image2)

**Figure 4.** Physical dimensions of the quadcopter.

### a. Flight controller

For these experiments, the Pixhawk flight controller, which is a high-performance autopilot-on-module, was chosen as the quadcopter’s flight controller. It is an open-source autopilot system for hobby and academic use. Its low cost, availability and widespread use make it ideal for use in this research effort. The Pixhawk flight controller features a comprehensive suite of sensors required
to achieve basic flight. This includes an Invensense MPU 6000 IMU (Inertial Measurement Unit), with accelerometers, gyroscopes, and magnetometers to measure body axis angular rates and translational acceleration. The magnetometer measures the earth’s magnetic field and is used to determine the orientation of the quadcopter relative to the earth-fixed reference frame. It also features a barometer to determine the altitude of the quadcopter. A subset of the specifications are listed in Table 2 below.

Table 2. Pixhawk flight controller specifications.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Processing Unit (CPU)</td>
<td>168 MHz Cortex-M4F</td>
</tr>
<tr>
<td>Input/Output</td>
<td>14 PWM/Servo outputs</td>
</tr>
<tr>
<td>Extra connectivity</td>
<td>UART, I2C, GPS</td>
</tr>
<tr>
<td>Power distribution</td>
<td>Redundant power supplies</td>
</tr>
<tr>
<td>Flight log</td>
<td>Pluggable microSD card</td>
</tr>
<tr>
<td>Inertial Measurement Unit (IMU)</td>
<td>Invensense MPU6000 (ST Micro 3-axis 14 bit accelerometer, 3-axis, 16 bit gyro)</td>
</tr>
<tr>
<td>GPS</td>
<td>3DR GPS module</td>
</tr>
</tbody>
</table>

b. Motor and ESC (Electronic Speed Controller)

The quadcopter is powered by a set of four KDA 20-22 L brushless outrunner motors, through four Plush 18 A ESCs and a power distribution board. A subset of the specifications of the motor and speed controllers is given in Table 3 below.

Table 3. Specifications of Motor and electronic speed controller (ESC).

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<thead>
<tr>
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<th>Motors Specifications</th>
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<td>KDA 20-22 L Brushless Outrunner Motor.</td>
<td>Plush 18 A ESC.</td>
</tr>
<tr>
<td>Kv</td>
<td>924</td>
</tr>
<tr>
<td>Operating Current</td>
<td>6–14 A</td>
</tr>
<tr>
<td>Max. Voltage</td>
<td>11 v</td>
</tr>
<tr>
<td>Size/Weight</td>
<td>28 × 32 mm; 56 g</td>
</tr>
<tr>
<td>LiPo 2–4 cells</td>
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<td>Size/Weight</td>
<td>24 × 45 × 11 mm/19 g</td>
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A ground pilot always maintains override authority during autonomous flight; in case of emergencies, the pilot recovers control of the quadcopter to bring it back to safety. A sample flight is shown in Figure 5 below.

![Sample GPS Flight Path](image)

**Figure 5.** Sample flight path of quadcopter. Note: Green: Start; Red: End.

For the above flight, the corresponding GPS coverage is shown below in Figure 6, in terms of the number of satellites seen by the GPS unit mounted on the quadcopter. This information is stored in the ‘GPS’ data variable.

![GPS coverage](image)

**Figure 6.** GPS coverage corresponding to the flight data shown in Figure 5.

The corresponding attitudes of the quadcopter for the flight shown in Figure 5 are shown below in Figure 7. The flight segment between the center of the “Figure-8” pattern and before the 5s hover maneuver prior to landing is marked by the dashed black line in Figure 7.
Finally, the RC outputs from the flight controller for the same flight are shown below in Figure 8. The RC outputs correspond to the output of the flight controller, in order to maintain desired attitudes and execute the “Figure-8” flight path, autonomously.

4. User Notes

Users need to note that the data stored in various variables are sampled at different frequencies. It would be useful to resample the data to a baseline frequency to enable analysis of the data. Except the IMU (inertial measurement unit), the sample frequency of most other sensors is 10 Hz, and the GPS
sensor is 5 Hz. For instance, we have resampled data from all other sensors to match the sampling
frequency of the IMU, which is 25 Hz. This information is summarized in Table 4 below:

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Original Sample Frequency</th>
<th>Resampled Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATT (Attitude)</td>
<td>10 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>CTUN (Altitude)</td>
<td>10 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>Curr (Current and Voltage)</td>
<td>10 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>IMU</td>
<td>25 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>IMU2</td>
<td>25 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>NTUN (Velocity)</td>
<td>10 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>POS (Position, filtered from GPS)</td>
<td>10 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>RCOU (Controller output)</td>
<td>10 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>GPS</td>
<td>5 Hz</td>
<td>25 Hz</td>
</tr>
</tbody>
</table>

Table 4. Sample rates of different sensors.

Supplementary Materials: Supplementary materials can be found at http://www.mdpi.com/2306-5729/4/1/39/s1. Data files: The files contain data from flight tests of a custom designed quadcopter, autonomously flying a figure-8 pattern, at a constant altitude.

Author Contributions: Conceptualization, S.G.; methodology, S.G.; Experiments, Y.B., resources, S.G.; data curation, S.G., Y.B.; writing—original draft preparation, S.G.; writing—review and editing, S.G.; visualization, S.G., Y.B.; supervision, S.G.; project administration, S.G.; funding acquisition, S.G.

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Conflicts of Interest: The authors declare no conflict of interest.

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