EXPERIMENTAL EVALUATION OF DRONE PROPULSION SYSTEM CHARACTERISTICS

O.V. Derhunov, S.V. Shenhur

Abstract: The report presents the methods, hardware, and software for experimental evaluation of propulsion system`s characteristics in light unmanned aerial vehicles (UAV). These characteristics include thrust, spin rate, the power consumption of the propulsion system and the level of generated vibrations. They indicate the overall quality of the propulsion system and its components. The General capabilities of the UAV depend on these characteristics.

Key-words: unmanned aerial vehicle, propulsion system, measurement, experimental evaluation.

1. Introduction

The importance of the topic follows from the fact that the application of light UAVs (also called drones) has dramatically increased over the several last years. A wide variety of tasks is solved with the help of drones: environmental monitoring, different objectives in the agricultural sector, surveillance in Police and Special Forces, technical diagnostics of industrial objects, personal aerial photo, and videography [1,2]. Drones have become a usual everyday tool for the various technical specialists. This became possible due to the availability of the simple ready-to-use and relatively inexpensive commercial products that can meet the needs of many different industries. At the same time, to solve specific problems, special UAVs with certain operational capabilities must be designed. This is especially important in scientific and experimental engineering fields. The key part of every drone is the propulsion system. Usually, it includes an electric brushless motor, a propeller, an electric battery and an engine speed controller (ESC). When an engineer designs a new drone, he has to choose from a wide range of different components the one that is the most suitable for the particular task [3]. And there is a significant problem. Motors differ from each other in a way not provided in the datasheets. They also have slightly different parameters, even in one batch from the same manufacturer. Propeller characteristics don`t always correspond to the documentation. Propellers from one batch are not identical, and the ones of the same type but from various fabricators differ a lot. This is especially true for low- and middle-cost solutions. According to the design experience, the obtained characteristics of the propulsion system may deviate from expected by 35%. Thus, the experimental testing of the propulsion system in order to determine its real characteristics is an important task in the design of light UAVs.

The main characteristics of the propulsion system are its thrust, motor spin rate and power consumption. To ensure the correct operation of the propulsion system the developer must check the temperature of the key components and the level of vibration in different working modes. Thus, testing workstation must measure:

– the thrust with the 2 kg nominal value and the 0,05 kg resolution;
– the brushless motor spin rate with the 40000 RPM nominal value;
– the current drain with the 30 A nominal value;
– the brushless motor temperature;
– the motor controller temperature;
– the vibration (acceleration) of the motor frame.

The goal of the work is the design of the computerized workbench for the experimental testing of a drone propulsion systems with an ability to measure specified characteristics.

2. Generalized structure of the workbench

To solve specified tasks the general structure of the computerized workbench is presented (figure 1). It includes relevant measurement channels (MC), microcontroller unit (MCU), wireless interface for measurement data transmitting, liquid crystal display (LCD), analog digital converter module (data acquisition module), personal computer (PC), and specialized software, both on PC and MCU sides.

Due to the overall computation capabilities and rich built-in peripherals, in the testing workbench was used ARM based MCU – STM32F051. It has 48 MHz clock, 16 channel 12-bit analog-digital converter (ADC), multiple general purpose input/output (GPIO) pins, and a variety of interfaces. MCU collects data from sensors, displays it on LCD, sends it to the PC via the USB or the wireless interface and controls the motor mode.

To control the testing operations and visualize the measurement data without the PC, the workbench includes a 5 inch color LCD based on human machine interface (HMI) technology from Nextion

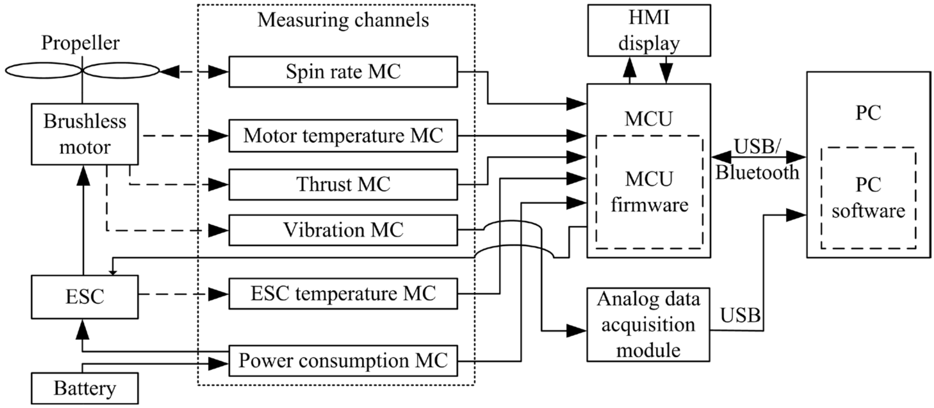

Fig. 1. The structural schematic of the testing workbench

Display company.

3. Measuring channels

The hardware of the workstation includes:

1. The measuring channel of the propulsion system thrust consists of the load cell, analog low-path filter, and integrated signal conditioning unit. The measurement range: 0...5 kg. The schematic diagram which explains the method of the thrust measurement is presented on the figure 2.

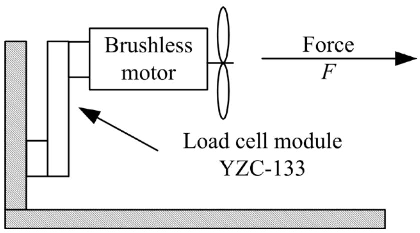

Fig. 2. The schematic diagram of the thrust MC construction

The load cell module consists of four tensoresistive sensors united under the Wheatstone bridge scheme. Such modules are used in the household electronic scales and are issued for various range values. In this work, a module with a nominal value of 5 kg, a nominal conversion factor of 1.0 ± 0.15 mV/V, and a total error of not more than 1.5%, was used. To transform the output signals from a load cell and transfer them to the MCU in a correct way, an integrated signal conditioning chip – HX711 was used. HX711 is a special 24-bit low noise ADC designed to drive the load cells signals. It has a serial peripheral interface (SPI) and could be easily connected to the MCU (fig. 3).

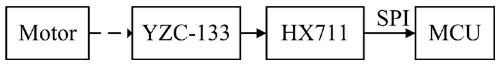

Fig. 3. The structural schematic of the thrust MC

The calibration of the thrust MC was performed by measuring the weight of the reference weights according to the generally accepted method of calibration of digital scales. The combined error of the channel does not exceed 2%, which satisfies the requirements.

2. The measuring channel of a motor spin rate consists of an optoelectronic spin rate sensor (OSS), comparator (COM) and ratemeter implemented in the microcontroller unit (fig. 4). The measurement range: 0...60000 rpm.

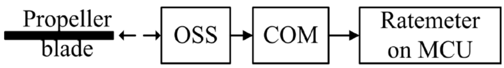

Fig. 4. The structural schematic of the motor spin rate measuring channel

The rate meter implemented on the microcontroller was checked by direct comparison of its indications with the indications of the laboratory rate meter (accuracy class 0.01). The error of the designed rate meter did not exceed 0.1% in the frequency range 40 ... 500 Hz.

3. The measuring channel of the motor temperature is based on the integrated digital contactless thermometer MLX90614. The sensor has a digital interface (I2C), thus no special signal conditioning circuit is needed. It`s main purpose: contactless monitoring of the working motor temperature. The

measurement range: 0...100°C.

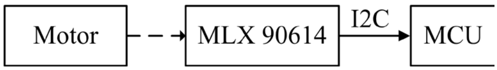

Fig. 5. The structural schematic of the motor temperature measuring channel

4. The measuring channel of the engine speed controller temperature consists of the K-type thermocouple and the integrated signal conditioning unit – MAX31855 (figure 6). The measurement range: 0...300°C.

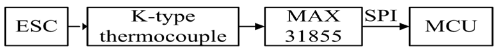

Fig. 6. The structural schematic of the ESC temperature measuring channel

5. The measuring channel of the motor power consumption consists of the Hall-effect current sensor ACS712 and he analog low-path filter (LPF) – figure 7. The measurement range: 0...30 A.

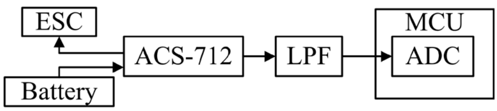

Fig. 7. The structural schematic of the motor power consumption measuring channel

6. The measuring channel of the vibroacceleration. It consists of the analog 3-axis MEMS accelerometer MMA7361 and the analog data acquisition module (DAQ). As the DAQ module the USB oscilloscope Analog Discovery was used in the workbench.

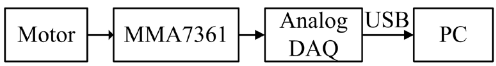

Fig. 8. The structural schematic of the thrust MC

4. Software

The software of the testing workstation is designed in the LabView environment. It performs the next tasks:

1. Communication and data exchange with hardware units of the testing workstation.
2. Monitoring of the current measured values.
3. Implementation of the automated testing of the propulsion system.
4. Statistical processing of the test results.
5. Statistical, spectral and time-frequency analysis of the vibration signals.
6. Automatic compilation of the reports.
7. User interface visualization.

5. Conclusions

With the help of the presented testing workbench it is possible to evaluate the characteristics of the various models of brushless electric motors, to select the most suitable propeller to achieve the desired performances, to estimate the flight time of the drone, to carry out the propeller and motor balancing procedure, to analyze the vibration of the propulsion system. These tasks are important in the design of new small-scale UAV for various fields.

6. References

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