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Measurement Capabilities

Introduction:

Characterizing drone drivetrains is essential for optimizing performance, increasing flight time, and improving efficiency, though it is a challenging task. Kairos Autonomi has a vested interest in performing these characterizations. Other works have detailed results of different motor and propeller combinations. Previous discussions have also been had on drone drivetrain characterization. This document aims to summarize the theory behind each measurement, discuss measurement reliability, and outline the set-up procedures.

Set-up:

As mentioned before characterization of the drivetrain performance requires many sensors. Each sensor requires careful calibration and consideration of the measurement method.

Table 1: A list of sensors and other tools used in characterization.

Sensor/Tool	Purpose
Thrust	A load cell positioned to measure force along the z-direction
Torque	A load cell positioned to measure force along the x-direction
RC Signal Converter	Converts RC signal into an analog signal
RPM Phototransistor	Used to measure RPM through change in voltage
Current Sensor	A closed loop closed magnetic proportion hall
Octo Cable	A cable that transfers analog signals from the sensors to the DAQ
Data Acquisition System (DAQ)	Collects and stores the analog signal in a format for analysis
Power Supply(s)	Power comes from 3 places to power various sensors
Servo Control	Controls the motor using RC signal
ESC/Power Board	Powers and controls motor based on input from the servo controller
Motor Arm	Distributes the torque force into the torque sensor
Torque Hold	Preloads torque sensor to increase precision of measurements
Motor Lever	Distributes the thrust force into the thrust sensor
Weight Transmitters	Converts data from the load cells into an analog signal
IR Thermal Camera	Uses Infrared Radiation to measure temperature of different parts
Bird Cage	A safety box designed to contain the motor while in operation

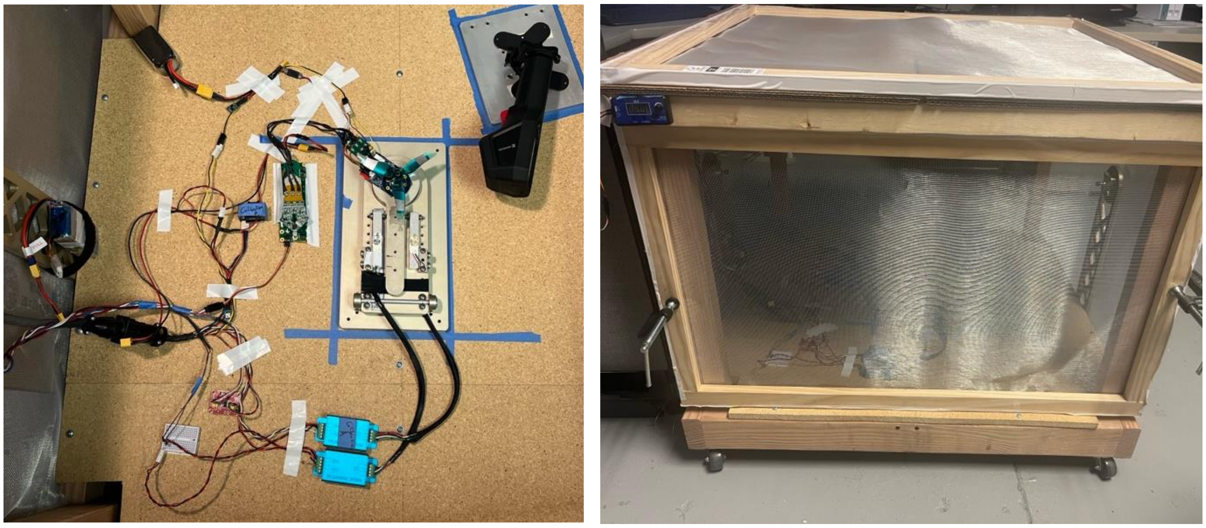


Figure 1: The above is an image of the setup. A shows outside the bird cage B shows inside. Detailed photos are given below labels the many components inside the bird cage. The Octo-Cable comes from inside the bird cage to the outside is meets with the data acquisition system. The Servo control also runs outside the bird cage for safe operation of the motor.

Figure 2: The power supply for the torque and thrust sensor and the data acquisition system (DAQ). Data saved on the DAQ before transfer to a computer where data analysis is performed, and data is stored in a larger database.

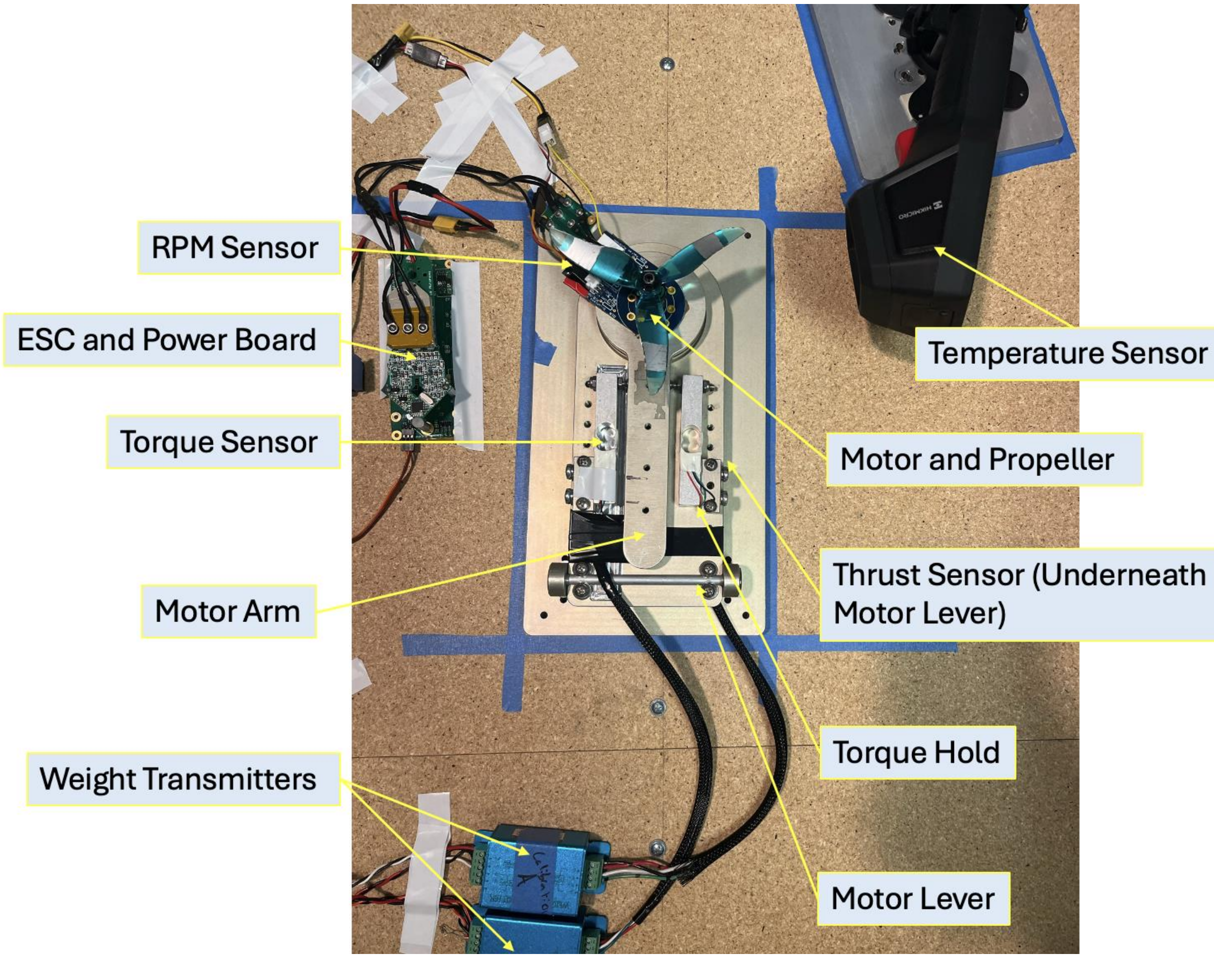


Figure 3: The inner right side of the bird cage.

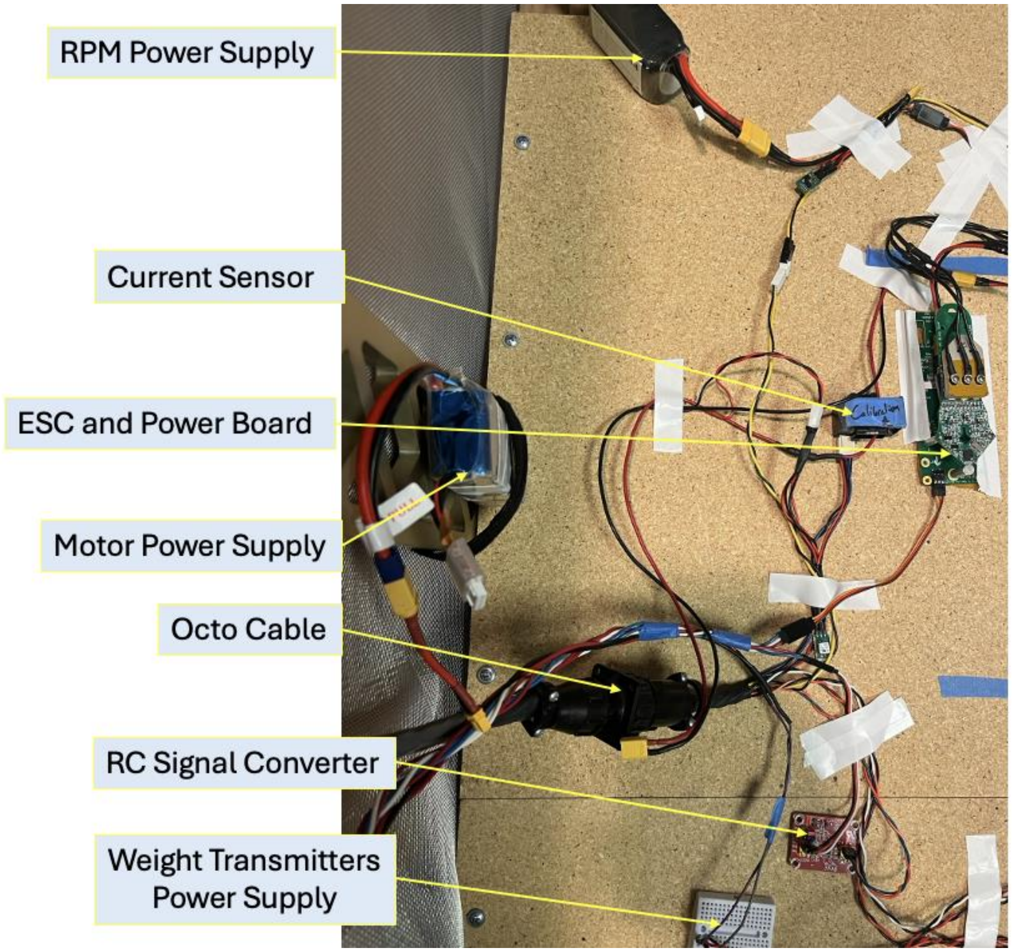


Figure 4: The inner left side of the bird cage.

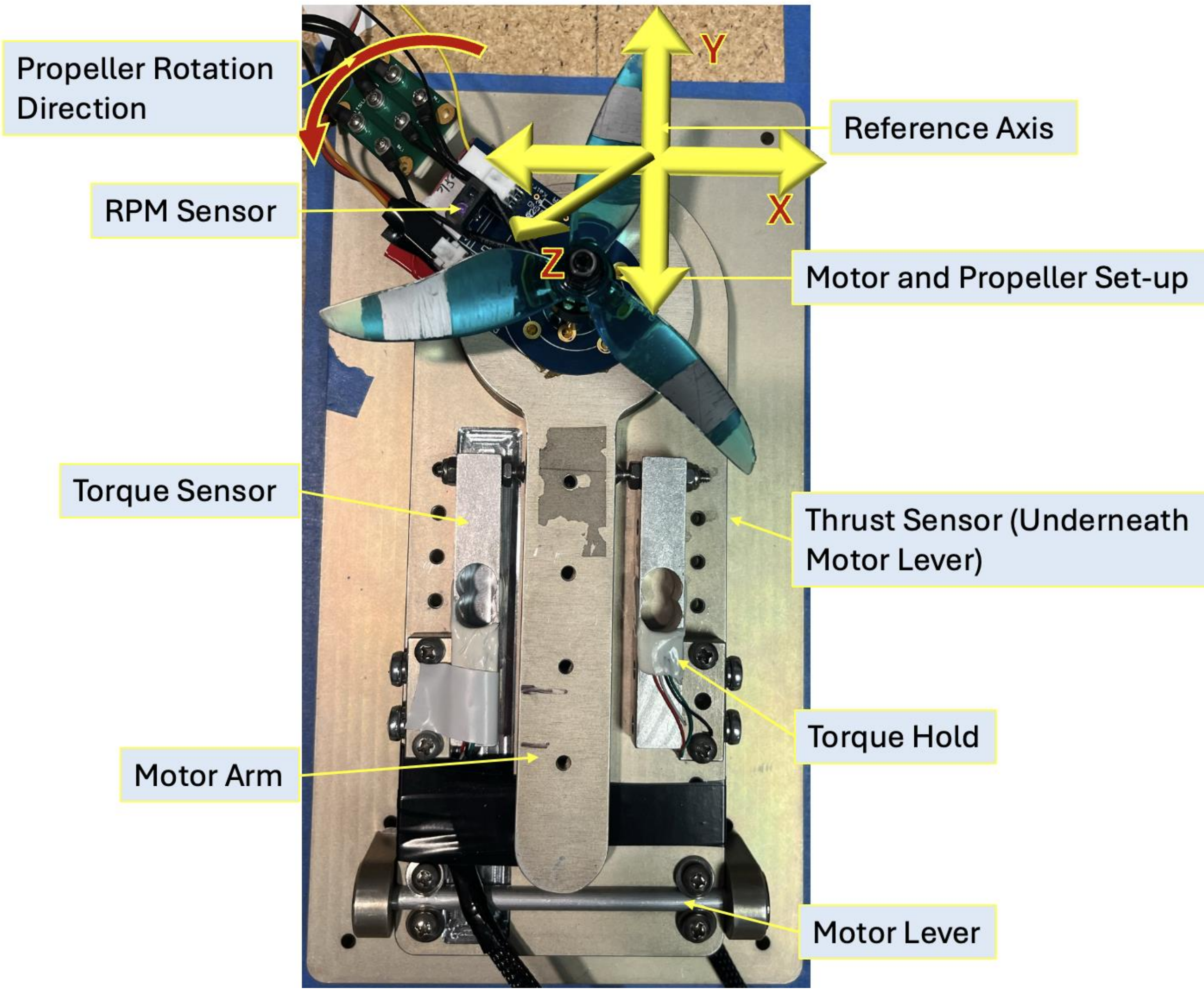


Figure 5: A close-up of the motor stand.

Non-Sensor Equipment

Certain equipment, though not directly related to sensors, is essential for data analysis, safety, or motor control. That equipment is discussed here and the primary function it serves is outlined.

Bird Cage:

The bird cage is a wood frame box with an aluminum mesh covering for safe operation of drones within. The solid particle board base provides a sturdy foundation for test to be performed. Since it is portable test can be set up with in the bird cage and allows for greater consistency in the measurement environment. The aluminum mesh ensures operator safter no matter the size of drone place within.

Data Acquisition System:

The Rigol M300 system collects and stores analog signal data. It features a voltmeter and digital display for real-time measurement readings and can measure frequency, allowing direct RPM measurement. Raw analog signal from the sensors, is transferred along the Octo-cable into the DAQ.

Motor Control:

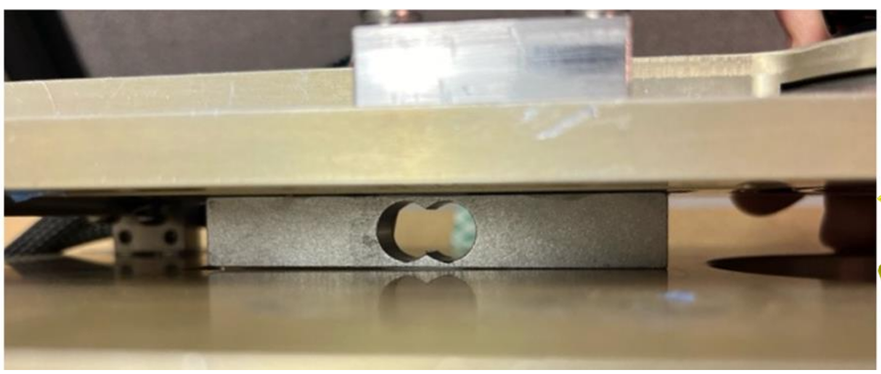
The motor and propeller are securely fixed to the motor arm. The motor's wiring is connected to an Electronic Speed Controller (ESC) and a power distribution board, which delivers power to the servo control. This set-up is powered with a 14.8 V battery.

Figure 6: Servo controller used to control the motor set-up.

Thrust Sensor:

Load cells generate signals that are transmitted to weight transmitters, which then convert these signals into analog data for the DAQ. The load cell for the thrust sensor measures forces along the z-axis. Force from the motor is distributed to the thrust load cell via the motor lever. Thrust generated by the motor pushes on the thrust load cell this allows for easy calibration of the load cell and weight transmitter through placement of the weights on the motor arm where the motors can be mounted.

The calibration ensures accurate and precise measurements of forces from 0.3 to 5.0 kilograms of force with an R squared value of 0.9997. With in this range the precent error is less than 4%. This load cell can be affected by wiring for the motor and RPM sensor. After a new motor has been mounted, a check should be done to ensure they are not affecting this load cell.



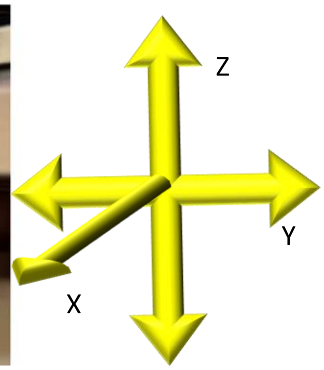


Figure 7: The image above shows the setup of the thrust sensor. The load cell is sandwiched between the motor lever and motor stand base.

Torque Sensor:

The torque load cell measures forces along the x-axis. Torque from motor rotation is distributed to the load cell via the motor arm. Key considerations include preventing over-rotation, ensuring correct distance and angle from the motor, and minimizing external forces from wiring.

Preventing Over-Rotation:

Over-rotation of the motor arm is prevented by the torque hold, ensuring the motor arm does not exceed its intended range of motion.

Ensuring Correct Distance and Angle:

Torque is measured from the force, radius, and angle. The distance from the center of the motor to the head screw of the torque load cell is measured with a caliper and found to be 0.04676 meters. The head screw is set to contact the motor arm at a 90º angle, ensuring accurate torque readings.

Minimizing External Forces from Wiring:

The motor must be wired to rotate counterclockwise, which pushes the motor arm into the load cell. Wiring can introduce external forces due to its spring-like nature, which depends on the thickness of the wiring. This can significantly impact torque measurements, so care must be taken to control wiring. Tape is used to secure wires, ensuring they do not impede the motor arm's free rotation, pull the motor arm into the load cell, or create excessive resistance.

Basic Checks for Each New Motor Installation:

1. The baseline torque must be maintained.
2. The analog voltage signal from the torque load cell must be greater than 0.030 mV with an RC value of 1200.

Calibration Process:

The load cell and weight transmitter are calibrated using a pulley system with hanging weights on the motor arm. This system ensures accurate and precise measurements of forces ranging from 0.03 to 1.0 kilograms of force, with a percent error less than 5%. The calibration curve has an R-squared value of 0.9994, indicating high accuracy.

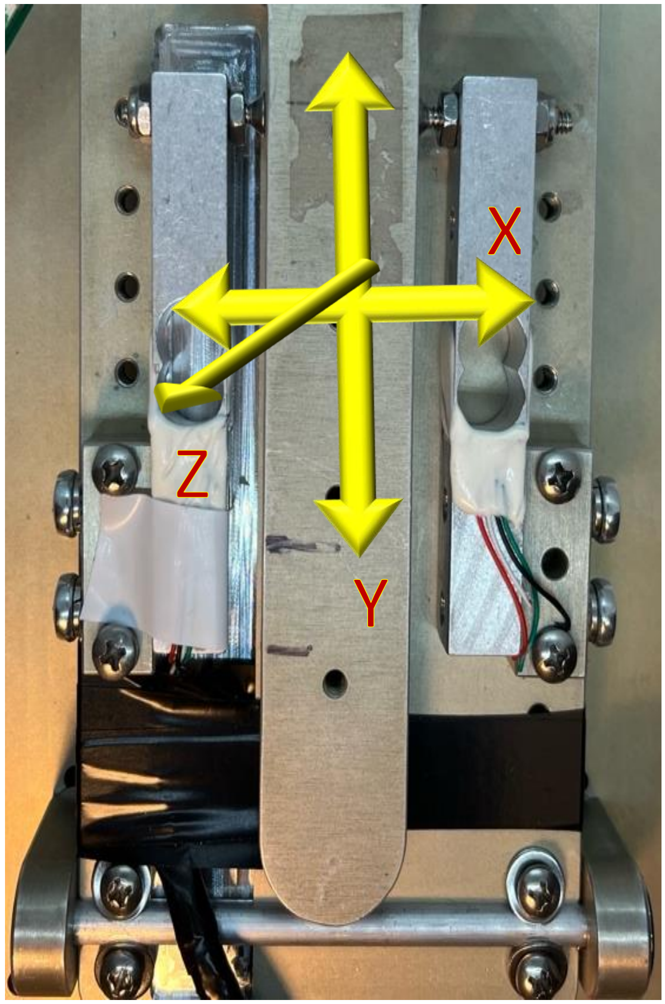


Figure 8: The setup of the torque sensor. The sensor set up is fixed to the motor lever. The motor arm rotates into the sensor. The spring preloads the sensor and prevents the rotation of the motor arm.

Current Sensor:

The current sensor used is a closed magnetic proportional system manufactured by Tamura, capable of measuring currents from -50 to 50 amps with over 95% accuracy. During testing, with our equipment, we observed that the percent error remained below 2% percent for currents under 10 amps.

This sensor is powered by a 5V voltage regulator from the motor power supply. A single battery lead passes through the sensor. Current is measured going into the power board. This means that current measurements account for all ESC functions.

Figure 9: The Tamura current sensor. Show as well is the split for the voltage measurement from the battery.

Voltage Sensor:

Voltage is directly sampled from the battery and fed into the DAQ, which records all other analog signals from the sensors. This measurement, taken before the current sensor and power board, allows calculation of the total electrical power leaving the battery. The DAQ boast of a voltage accuracy of 99.995% in the range of operation.

RPM Sensors:

The RPM sensor uses a small IR LED to emit infrared light, which reflects off objects and is detected by a phototransistor. The varying intensities of reflected light cause voltage changes that correspond to the frequency of the rotating object, allowing RPM calculation.

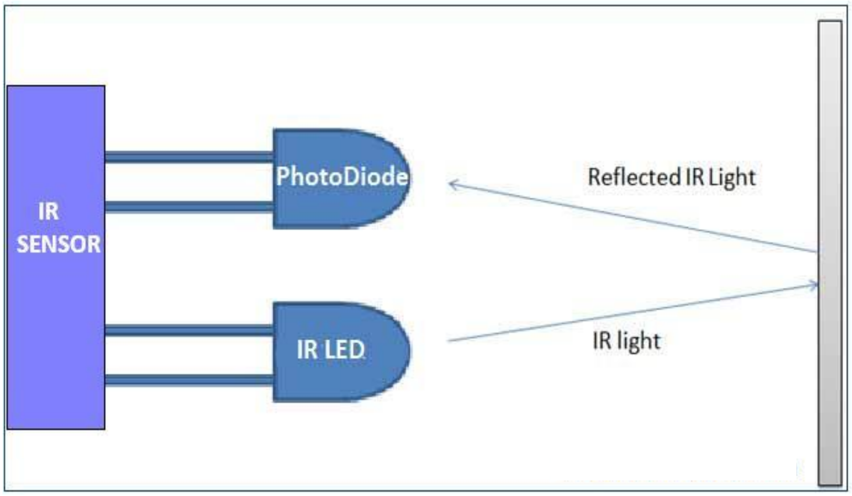


Figure 10*:* RPM Sensor Diagram and the IR phototransistor set-up.

RPM measurements must be optimized for each motor and propeller combination. Optimization is best done with an oscilloscope. The propeller is marked with a silver marking. The sensor is aimed up at the propeller blades which causes a change in voltage when passing the sensor. The voltage is registered at the DAQ which is set-up to measure frequency. The settings are given in table 2. In the data analysis the frequency is divided by the number of propeller blades because each propeller passing the sensor causes a change in voltage.

This method of frequency measurement has shown less than 5% variation between the different methods of measuring frequency. Two of those methods included use of digital tachometer, and oscilloscope.

Table 2: The settings for frequency measurement by the DAQ

Range	2V-20V	Use 20V unless it does not register otherwise use 2V
Filter	3Hz	Improves signal to noise ratio
Gate time	100ms	How long the voltage is monitored before frequency is determined
Delay	Auto	Helps with the timing of the measurement

Signal Converter:

The signal converter is crucial as it converts the servo signal into an analog voltage signal, enabling motor control. It has a calibration curve with an R squared value of 0.9967.

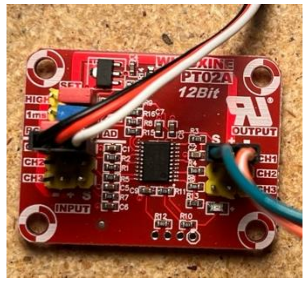


Figure 11: The signal converter circuit board.

IR Thermal Camera:

The Hikmicro B10 IR thermal camera is used to detect potential hotspots and monitor temperatures. Although it can observe multiple hotspots simultaneously, pinpointing exact temperatures of single components can be challenging. A temperature alarm is set to 250ºF to prevent overheating during tests.

Figure 12: The Hikmicro B10 IR camera.

Conclusion:

As can be seen the collection of motor efficiency data requires many different parts, each of which is essential in characterization of motor performance. Through use of the six sensors, the max thrust and RPM can be found. Using six different sensors, we can accurately determine maximum thrust and RPM. Careful data analysis allows for optimizing motor, propeller, and ESC combinations to maximize flight time and prevent overheating.

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Revisions

Name/Signature	Date	Description
Cameron H Miller	6-25-2024	Added Content