Multispectral sensors calibration for lightweight UAV

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Abstract. Using a suitable gimbal sensor, a lightweight multispectral sensor weight less than 500 g, such as visible imagery in the 400-700 nm (4000x3000 pixels), NIR imagery in the 520-920 nm region (2048 x 1536 pixels) and thermal 8-14µm (160x120 pixels) were placed on low-cost Hexacopter UAVs to perform aerial acquisitions of oil palm plant at very low altitude. Reliability data analysis is generated from the correction of undesirable and defect of sensor characteristics. Here, the sensor correction and calibration such as geometric, radiometric, vignetting, resolution and directional effects. Radiometric calibration using an upwelling water methodology where with thermosensor, the coefficient of determination, \( R^2 =1 \) and without thermosensor, \( R^2 = 0.9455 \). For multi-temporal or multi-sensor image analysis, relative DN-to-radiance radiometric calibration was performed by using the white material as calibration, then convert the other colored area without the material based on the ratio of the white panel area and the color reflected in that area and compatible with in-situ spectroscopy device.

1. Introduction
Researchers used Vertical Take-Off and Landing (VTOL) UAVs or rotary-wing UAVs, based on single, dual, triple, quad and multi-rotors systems [1,2,3,4]. Wester-Ebbinghaus [5] claim first to use a rotating wing, Schlüter Bell 222 for photogrammetric imaging with a maximum payload of 3kg (Rolleiflex SLX) and able to fly up to 100m. To reduced engine vibration, along with the helicopter body, they installed polystyrene along the walls and successfully reduce the vibrations. Sebastian Candiago [6] using UAV hexacopter ESAFLY A2500_H capable fly endurance 21 minutes along with the NIR sensor, Tetracam ADC Microsensor (90 grams) for analysis of cultivations vineyards and tomatoes, where the NIR sensor with three bands: Green, Red, and NIR (520-600, 630-690 and 790-900 nm). The UAV body materials from carbon with Delrin insert, with gross weight 5.4 kg with batteries and payload up to 3 kg. The analysis, vegetation health for each crop for precision farming outputs orthoimages based on analyzing different Vegetation Indices (VI) such as GNDVI, SAVI, and NDVI. With a cost less than $1,000, Chun [7] successfully developed a compact hexacopter with flexible gimbal payloads up to 700 g and fly up to 8 minutes. Commercial products UAVs, Parrot AR Drone [8] and DJI Phantom [9] payload less than 500 g and AcTec Pelican [10] maximum payload up to 650 g, but the price is £5,195 and is too expensive. Meanwhile, commercials gimbals, DJI Company [11] designed a
plastic gimbal for the lightweight GoPro camera and Photohigher Company [12], used carbon fiber used for the larger camera up to 1.8 kg. Since both commercial products are expensive, a creative hobbyist used plywood as gimbals.

2. Materials and Methods

2.1. Gimbal

This experiment used a sensor gimbal with two axes tilt mount which allows for stability of the picture and video recording capability with hexacopter UAV. The gimbal was made using high-quality carbon fiber and for vibration-dampening, rubber grommets were used for high picture and video quality. In this research, 2 types of the gimbal were used. One type of RGB / NIR sensor camera whiles other types of thermal sensor, as shown in (Figure 1 and 2). The wavelength for Canon SX230 sensor NIR from 670nm to 750nm, Canon SX260 above 750nm, Tetracam NIR 520 nm to 920 nm and thermal sensor 8-14 µm with temperature ranges from −20 °C to 250 °C was used.

Figure 1. RGB/NIR sensor with gimbal

Figure 2. Thermal sensor with gimbal
2.2. Flight Planning

Precise flight planning was necessary for the sensor and hexacopter UAV. The hexacopter UAVs was tested at an altitude of 338 m in order to ensure the stability of the UAV system. RGB Canon SX230 with focal length 5.2 mm were used and 234 images were captured with the area covered 2.08 km$^2$. The X and Y projection direction coordinate error is represented by ellipse shape, while Z error direction is represented by a different ellipse as shown in the Figure 3 legend.

![Figure 3. Sensor location and error estimation of UAV](image)

2.3. Sensor calibration

2.3.1 Thermal sensor. For a thermal sensor temperature of low-cost calibration, the range is between 0–100 °C. Based on the temperature measured by a thermal sensor of an upwelling flow of water, the level intensity of the temperature image color is achieved. Given the relatively expensive commercial blackbodies procedure, a new method is used without sacrificing the quality of calibration, which is replaced with water as the source of radiation ($\varepsilon = 0.98$). These experiments use color instead of gray color. A thermo-sensor Pasco Xplorer GLX with scaling 0.1 °C will provide accurate readings. This experiment takes about one hour and thirty minutes, where the sensor data calibration will be recorded every three minutes due to the sensor display keeps changing over time.

2.3.2 RGB and NIR sensor. These photogrammetric methods used Agisoft Lens software which uses a Brown's distortion pinhole camera model for lens calibration. The chessboard calibration pattern was used for an experiment using room light where intrinsic and extrinsic values are generated. The correction model specifies the transformation of the point into the $(X, Y, Z)$ coordinates which represent right, down and towards viewing. The $(X, Y, Z)$ coordinates can be calculated using equations:
\[ x' = x(1 + K_1 r^2 + K_2 r^4 + K_3 r^6) + P_1 (r^2 + 2x^2) + 2P_{1,xy} \]
\[ y' = y(1 + K_1 r^2 + K_2 r^4 + K_3 r^6) + P_1 (r^2 + 2y^2) + 2P_{2,xy} \]

where \[ r = \sqrt{x^2 + y^2}, \quad x = \frac{X}{Z}, \quad y = \frac{Y}{Z} \]

3. Results And Discussions

Upwelling water radiation results without thermo-sensor coefficient of determination, \( R^2 = 0.9455 \), while with thermo-sensor Xplorer GLX the coefficient of determination \( R^2=1 \) and blackbody radiators with R-squared, \( R^2=1 \). This analysis showed an upwelling water radiation with thermo-sensor also accurate comparable with blackbody radiator (Figure 4). Figure 5 shows results offset correction between MobIr M8 thermal and thermosensor where the coefficient of the determination result, \( R^2 = 1 \).

Figure 6 shows a radial and tangential distortion plot of Canon SX230HS NIR. Figure 7 shows a validation result of other colored DN with highest value 253 with a coefficient of determination, \( R^2=1 \).

All the diagnosis is recorded in telemetry logs such as Figure 8, which shows the telemetry logs for battery voltage, relative altitude, and airspeed, tested with or without gimbal for the RGB /NIR sensor. From the pre-flight, good results were achieved except for the battery voltage results (without gimbal) due to telemetry loss. This problem was fixed using the radio set at the Mission Planner calibration.

Figure 4. Upwelling water (\( \varepsilon = 0.98 \)) calibration with different temperature
Figure 5. Results offset correction between MobIr M8 thermal and thermosensor

Figure 6. Radial and tangential distortion plot of Canon SX230HS NIR

Figure 7. DN-to-Reflectance
4. Conclusions

With a sensitivity of less than 0.1 °C, the Uncooled thermal sensor can detect temperature differences between areas from the image generated. Environmental data, such as humidity, ambient temperature or the gap between the measured object is the most important or an accurate reading of thermal calibration. Since the error results only -2 °C (less than -5 °C tolerance), no MobIR M8 thermal needed for further adjustments. Based on both experiments, the coefficient of determination, upwelling water radiation without thermo-sensor R-squared, $R^2 = 0.9455$, with thermo-sensor $R^2 = 1$ and blackbody radiators with R-squared, $R^2 = 1$ were found.

From this analysis, upwelling water radiation with thermo-sensor also accurate comparable with blackbody radiator. The best practical calibration for upwelling water using thermal MobIR M8 sensor temperature range between 0–100 °C. The emitted heat provides the information for corrections to the measured probe temperatures. Hence the upwelling water method is cost-effective or practical for thermal calibration comparable with blackbody commercial Landcal
R1200P device. For DN-to-radiance, the data are taken with UAV altitude at 100 meters. After compared with other digital numbers, the results of DN-to-radiance is accurate, where the determination of the coefficient, $R^2=1$.

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