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Accurate Estimation of Water Temperature from UAV-mounted Thermal Camera: the Use of Generalized Additive Models and Dynamic Programming Algorithm to Correct for Vingetting Effect and Thermal Shift

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Abstract

Water temperature maps based on Unmanned Aerial Vehicles (UAVs)-thermal camera data have a significant role to study freshwater systems and inform for the potential thermal effects of any alteration. Nevertheless, the estimation of water absolute temperature (T_k) can still represent a problem when the accuracy needed must be < 1 °C. The vignetting effect and the thermal shift are two sources of bias in the estimation of water temperature. We present here a procedure that implement already developed methodologies with new techniques to produce thermal map with errors below 1 °C.

Keywords: freshwater, temperature, vignetting effect, thermal shift, UAVs.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) equipped with uncooled radiometric thermal cameras are accessible tools to explore rivers' water temperature with unprecedent resolution. Nevertheless, the estimations of absolute water temperature (T_k) can still represent a problem if is needed a high accuracy (i.e., error < 1 °C). Two significative sources of bias of the recorded thermal radiation are the so-called vignetting effect (i.e., the reduction of thermal radiation intensity towards the edges of the frame) and thermal shift\drift (i.e., the variation of the overall brightness temperature of the frame due to camera heating or internal camera correction) (Abolt et al. 2018); they can determine errors in estimation of water T_k up to 8 °C (Dugdale et al. 2019). The vignetting effect can be correct through the subtraction of a correction raster obtained in field using sources of uniform temperature (i.e., camera cap or thermal blackbody), but has been showed that the magnitude of vignetting effect can be air temperature and flight altitude dependent (Aragon et al. 2020). Thermal shift correction are based on field T_k measurement of points of known location or post processing approaches (Casas-Mulet et al. 2020; Abolt et al. 2018). The aim of our work is to implement already developed methods of correction with Generalized Additive Models (GAMs) for vignetting effect and dynamic programming for thermal shift correction in order to: (I) correct for the vignetting effect considering its dependence from flight conditions in filed; (II) correct for the thermal shift (or any fictitious variation of background temperature) with a post-processing method that release any assumption of thermal shift linearity and do not request extensive deployment of loggers other than the validation ones; (III) result in a final estimation of T_k with errors < 1 °C. The results here presented are based on four sets of radiometric JPG images (RJPG) captured with the DJI Zenmuse XT2 radiometric camera (640×512) over the Errochty Water and the Braan River (Scotland). Ten loggers were placed in the water for validation purposes during the flight.

2. VIGNETTING CORRECTION

Similarly to Abolt et al. (2018) the vignetting correction is performed by adding to each thermal image a correction raster (i.e., a raster which pixels values compensate the decreasing of thermal radiation due to vignetting) built using one of the frames captured by the drone during the flight (i.e., accounting for altitude and temperature effect). Specifically, it must be selected a frame with a relatively homogenous temperature (e.g., forest cover, water or grass field), and model its pixels raw value through a GAM with the form

$$\mathrm{raw}_i = f\,(x_i, y_i)\ , \tag{1}$$

where f is a thin plate splines with 100 knots and x, y is the position of the ith pixel. The relatively small number of knots has been chosen to capture the "overall trend" of the pixels' raw values variation and thus the vignetting effect. The pixels' value of the correction raster is computed as the difference between the maximum GAM-predicted pixels' value (assumed to be the point unaffected by vignetting) and each GAM-predicted pixel value.

3. THERMAL SHIFT CORRECTION

Vignetting corrected images are then imported in Agisoft Metashape producing an orthomosaic. Orthophotos are subsequently exported. We developed a dynamic programming algorithm, that generates thermal shift correction starting from a single corrected orthophoto (i.e., an orthophoto which scene include one of the deployed loggers and thus corrected in its raw values based on the logger's water T_k measurement during flight); subsequent images are iteratively corrected by compensate the difference in their mean raw value (computed on the overlapping part of the orthophotos) with already corrected images.

4. VALIDATION

Using vignetting and shift corrected images we built a final orthomosaic where the estimated T_k was validated using the average T_k recorded by validation loggers during flight (excluding the logger used in the shift correction). Specifically, we computed Mean Absolute Error (MAE), the Errors standard deviations (E-sd), the Root Mean Square Error (RMSE), and the correlation coefficient (r). In all the four dataset MAE < 0.7 °C, E-sd < 0.55 °C, RMSE < 0.53 °C, and r > 0.91.

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