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FOV direction and image size calibration of Fluorescence Detector using light source on UAV

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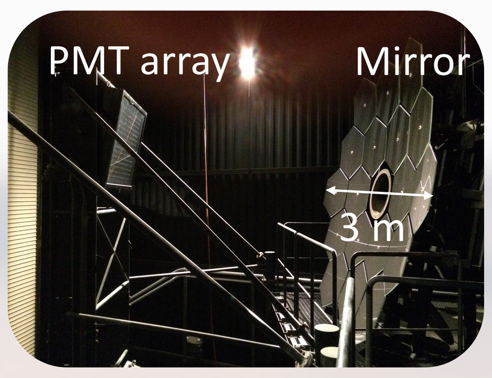
Abstract

In the Telescope Array (TA) experiment, we have been observing cosmic rays using a Fluorescence Detector (FD). More than 10 years have passed since we started this observation, and the accuracy of the observation has become more important than ever. We have developed the **"Opt-copter"** as a calibration device for the FDs. The Opt-copter is an unmanned aerial vehicle (UAV) equipped with a light source and can fly freely within the FD's field of view (FOV). In addition, the Opt-copter is equipped with a high-precision RTK-GPS, which enables it to accurately determine the position of the light source in flight. With this device, we can obtain detailed information on the optical characteristics of the FD. So far, we have reported on the configuration of the device and the analysis of the FOV direction. In this presentation, we will report on the new FOV analysis and image size on the surface of the PMT array analysis.

Opt-copter overview

Fluorescence Detector (FD)



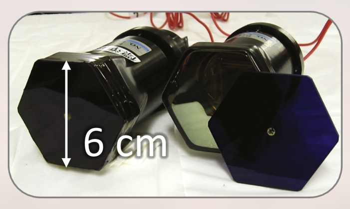
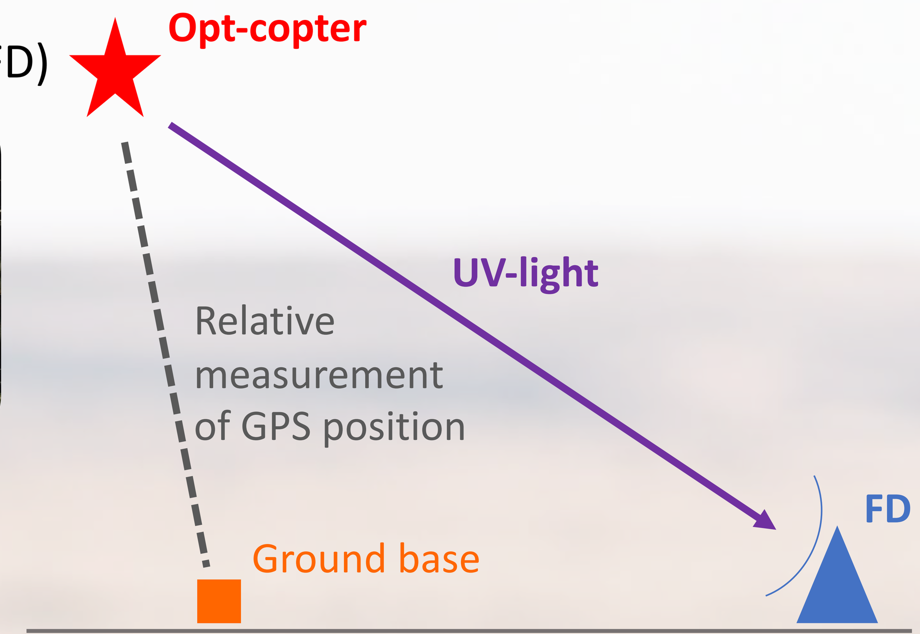


Photo multiplier tube (PMT)



The purpose of the Opt-copter is to grasp the optical properties of the FDs. The Opt-copter consists of a UAV, a light source, and a high-precision RTK-GPS module. This device is flown 300 m away from the FD during the measurement. The light source is a UV-LED with a wavelength of 375 nm, which emits light at 10 Hz ~ 30 Hz. The positional accuracy of RTK-GPS is typically 10 cm, which corresponds to a directional accuracy of 0.02 degree. The FD focuses the light with a compound spherical mirror consisting of 18 segmented mirrors, and the light is detected by 256 PMTs. The width of each PMT is about 6 cm, and the viewing angle is about 1 degree. The center of gravity (COG) is calculated from the amount of light received by each PMT and its center position. The COG is used as the light-receiving position of the FD.

FOV direction analysis

Since the image size on the surface of the PMT array is small compared to a window size of the PMT, the COG is biased towards the center of the PMT which contains the main part of the image. Fig. 1 is the RTK-GPS positions projected on the focal plane and the COG positions. Fig. 2 is the difference between the RTK-GPS position and COG position in Fig. 1. And in Fig. 2, the red point is the mean of the green points. **By statistically comparing the RTK-GPS position and the COG position as shown in Fig. 2, we can estimate the difference of the actual FOV direction to the assumed FOV direction of the FD. We performed this analysis for all the FDs of the BR station. The results are shown in Table 1.** It was found that most of the FDs were pointing downward more than expected. We also performed this analysis for each of the FD04 ~ FD07 measurement data in 2018 and 2019 to check for repeatability. The systematic error in this analysis is 0.03 degree, based on the systematic error in GPS position (0.02 degree) and FD (0.02 degree).

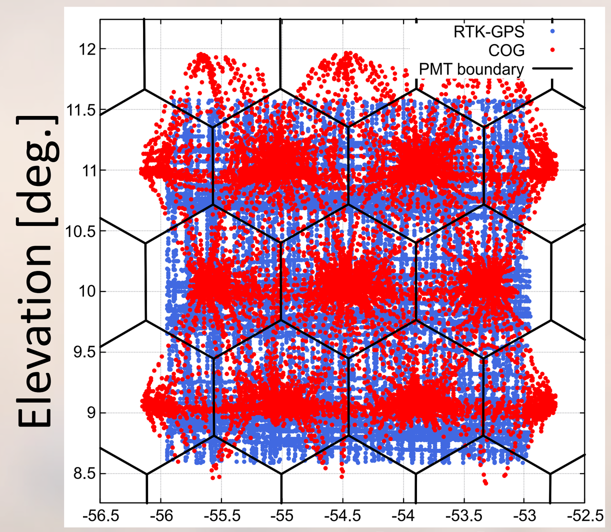


Fig. 1: The RTK-GPS position and the COG position at the center of the FD07's FOV.

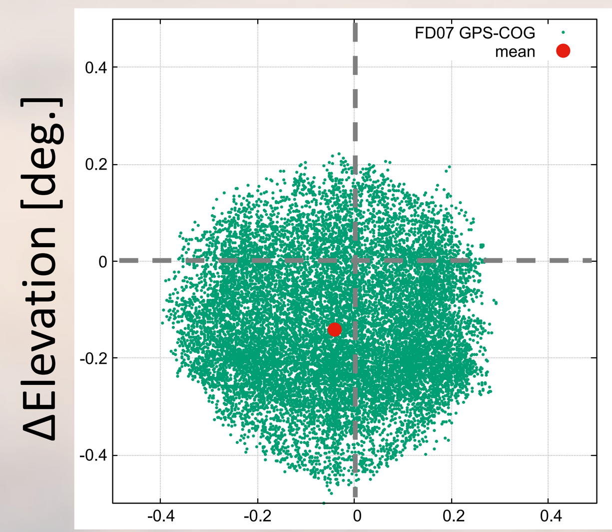


Fig. 2: The difference between the RTK-GPS position and the COG position in Fig. 1.

Table 1. The results of FOV direction analysis of the BR station (2018).

	FD00	FD01	FD02	FD03	FD04	FD05	FD06	FD07	FD08	FD09	FD10	FD11
ΔAzimuth [deg.]	0.05	0.00	0.04	0.04	0.04	0.02	0.01	-0.04	0.01	-0.05	-0.02	0.01
ΔElevation [deg.]	0.11	-0.04	0.02	-0.03	-0.04	-0.12	-0.05	-0.14	-0.12	-0.19	-0.14	-0.15

Image size on the surface of the PMT array analysis

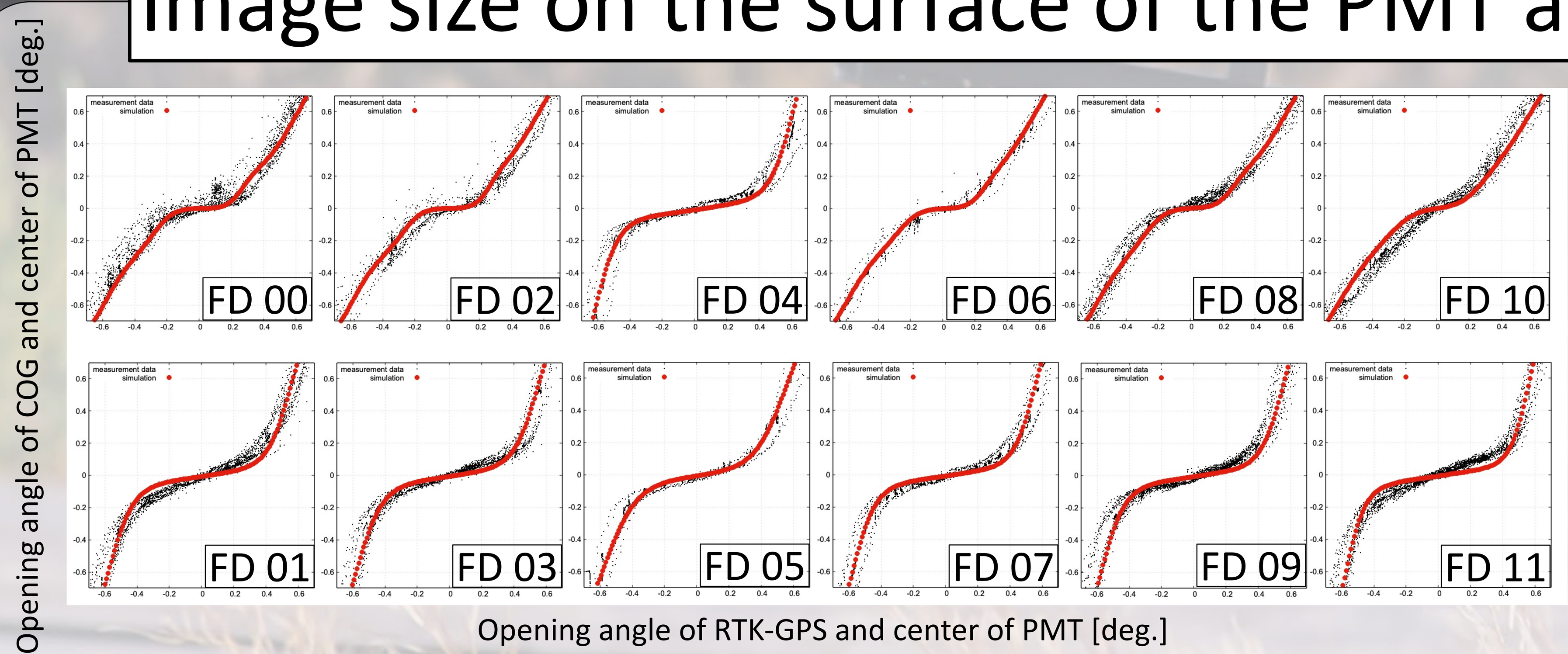


Fig. 3: The relationship between the RTK-GPS position and the COG position at the center of the FOV for each FD of the BR (azimuthal).

We focused on the relationship between the RTK-GPS position and the light-receiving COG at the center of the FD's FOV as shown in Fig. 3. This relationship becomes stair-step with smaller image size on the surface of the PMT array. When the measurement by Opt-copter is simulated, the image size on the surface of the PMT array can be evaluated by comparing the simulation with the measurement data as shown in Fig. 3. **Fig. 3 shows that the simulation roughly reproduces the measurement data and that we have a good understanding of the FD.** A simple adjustment by eye level was also made to make the simulation further reproduce the measurement data, as shown in Fig. 4. The hit map of the photons in the simulation changed as shown in Fig. 5, and the image size on the surface of the PMT array was smaller than expected. In this way, **the simulation can be made closer to the measurement data by using the Opt-copter. In the future, we will continue to analyze the effects of aberrations as well as the image size on the surface of the PMT array.**

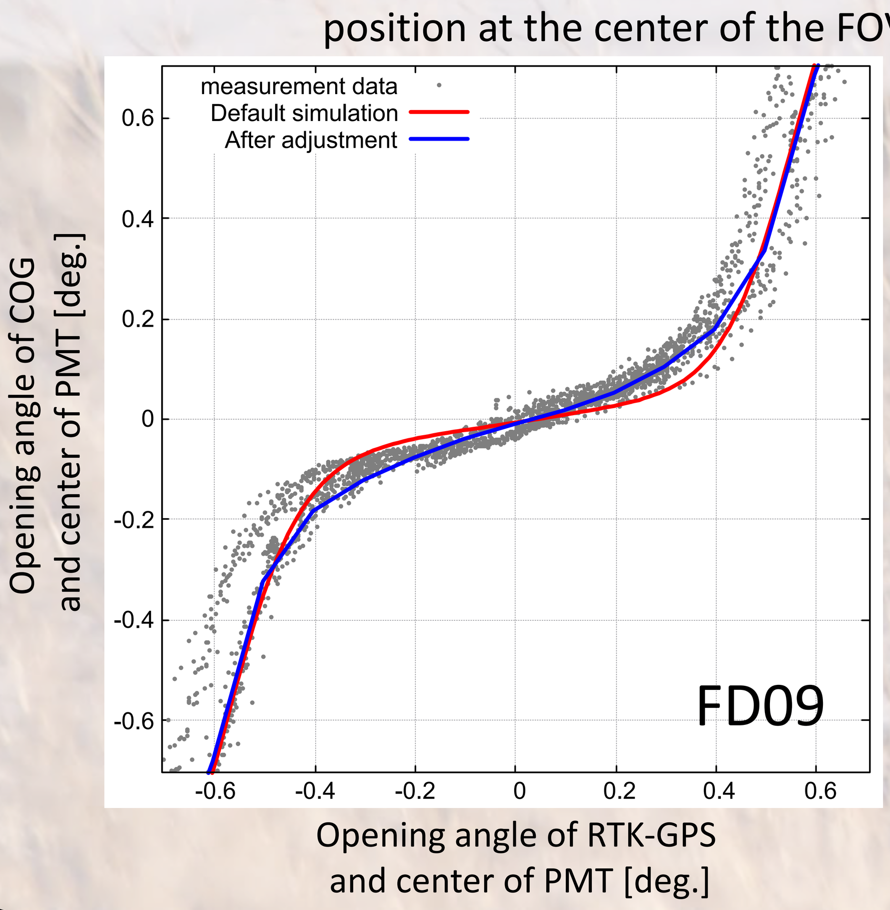


Fig. 4: The changes in the relationship between the RTK-GPS position and the COG position before and after the adjustment (azimuthal).

The axis in Fig. 3 and Fig. 4 shows the azimuthal opening angle between the RTK-GPS or COG position and the center of the PMT closest to the center of the FD's FOV.

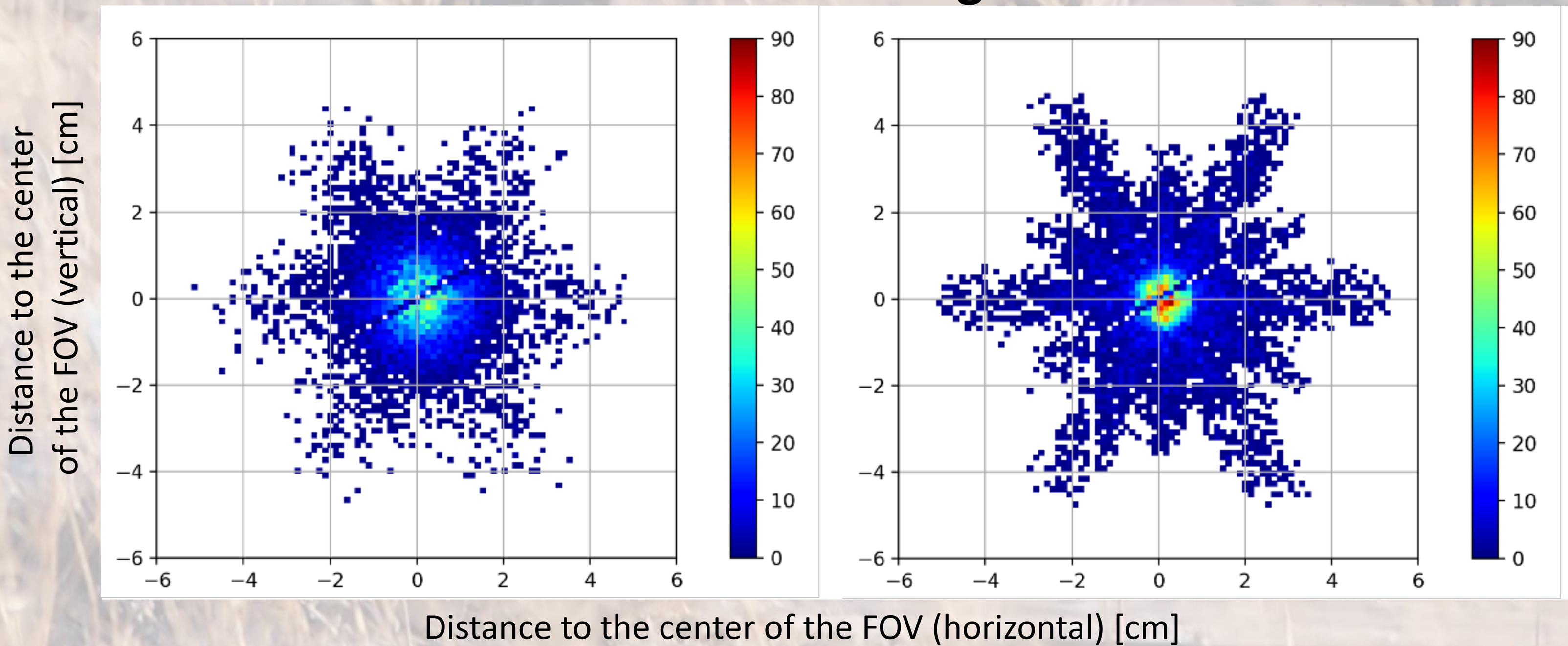


Fig. 5: The hit map of photons at the center of the FD09's FOV. Left: Before adjustment. Right: After adjustment. Caution: These are affected by the PMT boundary.