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Stereo Cameras for Clouds (STEREOCAM) Instrument Handbook

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ARM CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

A	amperes
Ah	ampere hour
ARM	Atmospheric Radiation Measurement
3D	three-dimensional
DOE	U.S. Department of Energy
doi	Digital Object Identifier
ft	feet
km	kilometer
m	meter
mA	milliampere
mm	millimeter
SGP	Southern Great Plains
SNR	signal-to-noise ratio
USB	Universal Serial Bus
V	volts
VDC	volts direct current
W	watts

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1.0 General Overview

The three pairs of stereo camera setups aim to provide synchronized and stereo calibrated time series of images that can be used for three-dimensional (3D) cloud mask reconstruction. Each camera pair is positioned at approximately 120 degrees from the other pair, with a 17º-19º pitch angle from the ground, and at 5-6 km distance from the U.S. Department of Energy (DOE) Central Facility at the Atmospheric Radiation Measurement (ARM) user facility Southern Great Plains (SGP) observatory to cover the region from northeast, northwest, and southern views. Images from both cameras of the same stereo setup can be paired together to obtain 3D reconstruction by triangulation. 3D reconstructions from the ring of three stereo pairs can be combined together to generate a 3D mask from surrounding views. This handbook delivers all stereo reconstruction parameters of the cameras necessary to make 3D reconstructions from the stereo camera images.

2.0 Contacts

2.1 Mentors

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2.2 Vendors

Each standalone camera setup is constructed at the ARM SGP site by using the following main components from the listed vendors.

Camera components:

StarDot Technologies
6820 Orangethorpe Avenue
Building H
Buena Park, CA 90620

info@stardot.com
http://www.stardot.com

Solar power components:

Northern Arizona Wind & Sun
4091 E. Huntington Drive, Suite B
Flagstaff, AZ 86004
http://www.solar-electric.com

Computer:

Moxa
Corporate Plata
601 Valencia Avenue, Suite 100
Brea, CA 92823
usa@moxa.com
https://www.moxa.com

3.0 Instrument Description

Figure 1. (Left) STEREOCAM in use at the ARM SGP site. (Right) STEREOCAM in carrying case.

Each stereo camera pair consists of two 5MP StarDot Netcam cameras, each mounted on a 7-ft-tall pole with a 500-600 m separation (baseline). Cameras are equipped with 4.5-13 mm varifocal StarDot 5MV4513CS lenses. Each camera is connected to a minicomputer, Moxa V2201, which controls image capture and temporarily stores data files. The computer establishes network connectivity through a CradlePoint IBR 600LPE cellular modem for data transfer and monitoring and assures precise time synchronization by use of a Garmin 18x PC GPS puck. Each stereo setup runs on solar power that is composed of two 145 W panels, a 12V 200Ah battery and a Morningstar MPPT 25A charge controller. The locations of the camera setups are listed in Table 1.

Table 1. Stereo setup locations.

Camera site	Latitude (N°)	Longitude (W°)	Altitude (m)
SGP/E43a	36.63704	97.53817	311
SGP/E43b	36.64056	97.53435	310
SGP/E44a	36.63705	97.43015	319
SGP/E44b	36.63360	97.42650	321
SGP/E45a	36.54990	97.47970	317
SGP/E45b	36.54950	97.48550	319

4.0 Historic Background

N/A

5.0 Measurements Taken

The main datastream acquired by each setup is the series of images at 2592x1944 pixel resolution stored in jpeg format. Images are acquired at 20-second intervals during the day and at six-minute intervals during the night. In addition to these images, auxiliary measurements corresponding to power system status as listed in Table 2 are taken hourly.

Each camera pair is stereo-calibrated; the calibration parameters are described in Section 6.5. These parameters can be used to obtain 3D cloud point reconstruction by matching pixel pairs on the stereo calibrated images (Bradski and Kaehler 2008, Hartley and Zisserman 2004, Oktem et al. 2014).

An automatic cloud point matching and 3D cloud point reconstruction algorithm has been developed by the mentors and is currently being tested for the three pairs of stereo cameras. The algorithm generates cloud point coordinates, cloud base heights and cloud top heights. These measurements will later be available at the ARM Data Center as value-added products after they are fully tested and verified.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

Datastreams are named as follows:

- sgpstereocamxE4y.YYYYMMDD.hhmmss.jpg, for the jpeg image files
- sgpstereocamxmovieE4y.YYYYMMDD.hhmmss.mpg, for a movie generated from images at one-frame-per-two-minutes interval.

- sgpstereocamxauxE4y.20170811.000501.nc, for the auxiliary power system status measurements (see Table 2).

x is either a or b, referring to one of the two pairs at the site E4y, y being 3,4, or 5.

6.2 Data Ordering

Search for “stereocama” or “stereocamb” at https://www.archive.arm.gov/discovery/#v/rersults/s/finst::stereocam

6.3 Data Plots

Go to http://plot.dmf.arm.gov/plotbrowser/

Scroll down for “SGP” at “Search Site” tab and “sgpstereocama” or “sgpstereocamb” at “Datastream” tab.

Table 2. Variable names and descriptions for the auxiliary measurements.

Variable name	**Unit**	**Description**
battery_voltage	V	Battery voltage measured at the battery terminals
load_voltage	V	Output voltage measured at the load terminals
load_current	A	Current out of the load terminals
battery_temperature°	°C	Battery temperature
ambient_temperature°	°C	Ambient temperature sensed by the charge controller
remote_temperature°	°C	Temperature of the remote temperature sensor
charge_state	NA	Flag describing the battery charge status
charge_fault	NA	Flag describing the battery fault status
load_state	NA	Flag describing the load status
load_fault	NA	Flag describing the load fault status
power_output	W	Charger output power
sweep_Vmp	V	Maximum power voltage of the solar array during the last sweep
sweep_max_power	W	Maximum output power during the last sweep

Variable name	Unit	Description
daily_battery_voltage_min	V	Daily minimum battery voltage
daily_battery_voltage-max	V	Daily maximum battery voltage
daily_Ah_charge	Ah	Total charge during the day in amp-hours
daily_Ah_load	Ah	Total load during the day in amp-hours
enclosure_temperature	°C	Temperature inside the camera enclosure

6.4 Data Quality

The image data quality is judged subjectively by the sharpness of images and metadata information collected with the images. Environmental factors such as rain or light may temporarily impact the data quality during the day or the season. In case of rainy weather conditions, rain drops on the camera screen will distort images. Heavy rain may result in complete visibility loss. Environmental light also affects the quality of the images, with higher signal-to-noise ratio (SNR) at dimmer light.

6.5 Calibration Plan

For an image acquisition at the best-possible quality, each camera lens is manually adjusted to focus at distant objects. Focus adjustment is performed after the field of view of each (varifocal) lens is adjusted at approximately 75°. Once adjusted, these parameters are not expected to change by time.

At 75º field of view, lens distortion becomes highly noticeable in the captured images. Images are stored as captured, i.e., without any lens distortion correction applied. Table 3 lists intrinsic camera parameters that can be used in a software tool such as OpenCV (OpenCV 2017) to correct images for lens distortion (Bradski and Kaehler 2008, Hartley and Zisserman 2004). The intrinsic camera parameters in Table 3 are obtained through intrinsic camera calibration by use of a checkerboard pattern (Bradski and Kaehler 2008). These parameters do not change for a fixed-lens adjustment, hence intrinsic camera calibration needs to be updated only if the camera focus or field of view is changed.

For stereo processing, each stereo camera pair has to be stereo calibrated, i.e., extrinsic camera parameters have to be identified. The extrinsic camera parameters are listed in Table 4, where focus and principal point parameters are for distortion-corrected images. Extrinsic camera parameters need to be updated only if the camera positions or headings change. The camera views are constantly monitored by the mentor and the calibration parameters will be updated if any change in position/heading is detected.

Table 3. Intrinsic camera parameters before lens distortion correction.

Camera site	k_1	k_2	k_3	p_1 x (1e-3)	p_2 x (1e-3)	f_x	f_y	p_x	p_y
SGP/E43a	-0.37507	0.20991	-0.07293	0.47016	0.22249	2144.73	2143.83	1214.88	904.42
SGP/E43b	-0.37813	0.23625	-0.09808	-0.29191	1.29736	2111.34	2108.92	1260.71	966.21
SGP/E44a	-0.38075	0.23672	-0.10839	-1.07151	2.05111	2175.38	2174.61	1169.49	926.21
SGP/E44b	-0.37925	0.22109	-0.08296	1.11171	-0.20639	2156.15	2155.45	1271.51	909.44
SGP/E45a	-0.37728	0.23040	-0.09825	-0.20639	-1.06639	2130.12	2130.35	1282.82	1015.46
SGP/E45b	-0.37669	0.21461	-0.07753	-0.01635	0.23143	2133.99	2133.31	1237.26	935.99

Table 4. Intrinsic and extrinsic camera parameters after lens distortion correction.

Camera site	Azimuth (from N)	Elevation (from the ground)	Roll angle	f_x	f_y	p_x	p_y
SGP/E43a	134.77	18.66	1.12	1608.2	1590.43	1172.93	884.68
SGP/E43b	137.49	18.57	-0.38	1589.96	1615.71	1245.97	961.46
SGP/E44a	232.33	18.98	-0.5	1530.11	1483.47	1056.78	870.48
SGP/E44b	237.08	18.56	-0.38	1628.82	1634.03	1255.56	896.02
SGP/E45a	356.8	17.5	0.05	1575.81	1581.21	1260.76	1032.7
SGP/E45b	358.55	18.55	-0.87	1605.81	1588.06	1205.97	923.05

7.0 Date of Calibration

Lens and position adjustments were completed on August 31, 2017.

8.0 Detailed Description of the Instrument

StarDot Netcam CAM-SEC5-NL

StarDot Lens, LEN-5MV4513CS

9.0 Target Measurement Uncertainty

N/A

10.0 Date for Next Calibration

As needed.

11.0 Entries for Calibration Checks

N/A

12.0 Entries for the Calibration Results and Method of Error Assessment

N/A

13.0 List of Calibration Certificates Provided with Calibrations

N/A

14.0 Technical Specification

- StarDot Netcam CAM-SEC5-NL
  - Image sensor: RGB, CMOS, 5MP 2592x1944, ½"
  - Exposure: 0.001 second – 0.68 second
  - Image compression: jpeg, Motion-jpeg
  - Dimensions: 82 mm W x 57 mm H x 112 mm L
  - Weight: 14 ounces
  - Power requirements: 500 mA @ 12 VDC
- StarDot lens LEN-5MV4513CS
  - Focal length: 4.5-13mm
  - Lens stop: f1.8
  - Lens format: ½"
  - Lens mount: CS
  - Horizontal field of view: 90º-31º

14.1 Units

N/A

14.2 Range

N/A

14.3 Accuracy

N/A

14.4 Repeatability

N/A

14.5 Sensitivity

N/A

14.6 Uncertainty

N/A

15.0 Instrument System Functional Diagram

N/A

16.0 Instrument/Measurement Theory

N/A

17.0 Setup and Operation of Instrument

Each stereo camera is a part of a standalone setup that is powered by a deep-cycle battery charged by two 145 W solar panels (Figure 1) and establishes network connectivity through a CradlePoint IBR 600LPE cellular modem. Figure 2 displays an electrical enclosure that holds the charge controller (monitoring and regularizing power to the system), cellular modem, and a minicomputer. The computer instructs the camera to capture jpeg images at regular intervals – 20 seconds during the daytime and 6 minutes during the nighttime – and temporarily stores image and auxiliary data.

Auxiliary data is collected from the charge controller through a meter bus with an RS232 interface and from a USB thermometer inside the camera enclosure. Images from all cameras of the stereo ring must be time synchronized within one second. A GPS puck is a part of the setup to ensure precise time synchronization. The minicomputer resets its time through the GPS puck every day at midnight.

Figure 2. A camera setup onsite. Two solar panels mounted with a top-of-pole rack, an electrical enclosure beneath the solar panels, and the camera enclosure tilted approximately 18°from the ground.

Figure 3. Interior of the electrical enclosure of a camera setup. A charge controller, a cellular modem, a minicomputer, and circuit breakers and fuses are enclosed in this box, placed beneath the solar panels as shown in Figure 2.

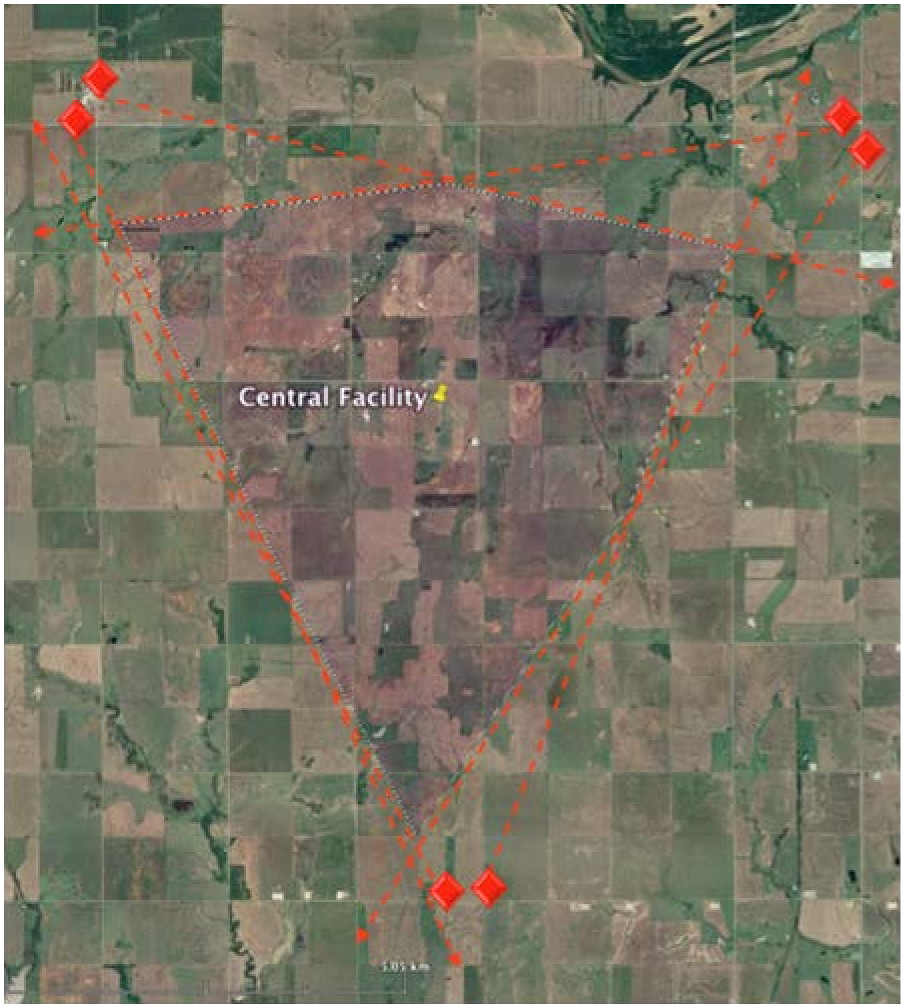

Figure 4. The positions of three camera pairs surrounding the SGP Central Facility from northwest (E43), northeast (E44), and southern (E45) views. The dashed lines show the field of view for each camera pair. The light red shaded region represents the common field of view for all three pairs.

18.0 Software

N/A

19.0 Maintenance

Inspect image videos daily for camera focus/heading/view change and for spider webs in front of the camera enclosure screen.

Inspect the battery monthly for cracked or bulging cases, and corroding terminals.

Inspect all wiring annually.

Inspect enclosures for nesting insects annually.

20.0 User Notes and Known Problems

See section 6.4 Data Quality.

21.0 Frequently Asked Questions

N/A

22.0 Citable References

Bradski, G, and A Kaehler. 2008. *Learning OpenCV: Computer Vision with the OpenCV Library*. O'Reilly Media, 580 p.

Hartley, RI, and A Zisserman. 2004. *Multiple View Geometry in Computer Vision*. Cambridge University Press, Cambridge, England, 654 p.

Oktem, R, Prabhat, J Lee, A Thomas, P Zuidema, and DM Romps. 2014. "Stereophotogrammetry of Oceanic Clouds." *Journal of Atmospheric and Oceanic Technology* 31(7): 1482–1501, doi:10.1175/JTECH-D-13-00224.1.

OpenCV. 2017. "Open Source Computer Vision Library", https://opencv.org/

23.0 Historical Changes

N/A

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