Autonomous meridian scanning photometer for auroral observations

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Abstract. The system design of an automated meridian scanning photometer developed for the Canadian Auroral Network is described. The instrument operates unattended year round in an arctic environment. The instrument has considerable on-board processing capability for data analysis, communication functions, and fail-safe operation.

Subject terms: photometers; meridian scanning; automation; aurora; cold environments.

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1. INTRODUCTION

A meridian scanning photometer (MSP) has been developed by Bomem Inc. in conjunction with the National Research Council Canada (NRCC) for use in studies of the aurora borealis. These studies are under the auspices of the Canadian Auroral Network for the Open Program Unified Study (CANOPUS). The auroral network consists of a complement of instruments, including the MSP, placed at various arctic sites near a single geomagnetic longitude.[1]

The MSP is an evolved version of instruments previously developed at NRCC and elsewhere.[2,3] It is the most recent scanning photometer design for use in a program of multistation observations.[4,5] Its principal advances include significant on-board processing power for automated data collection, data treatment, and communication functions and environmental packaging to allow year-round unattended operation. The instrument has extensive self-monitoring and control capabilities to ensure fail-safe operation.

2. SYSTEM DESCRIPTION

2.1. Operation

The CANOPUS MSP measures sky brightness within a 4° circular field of view along a north-south arc, or meridian. At each of seven wavelengths, 510 measurements are made

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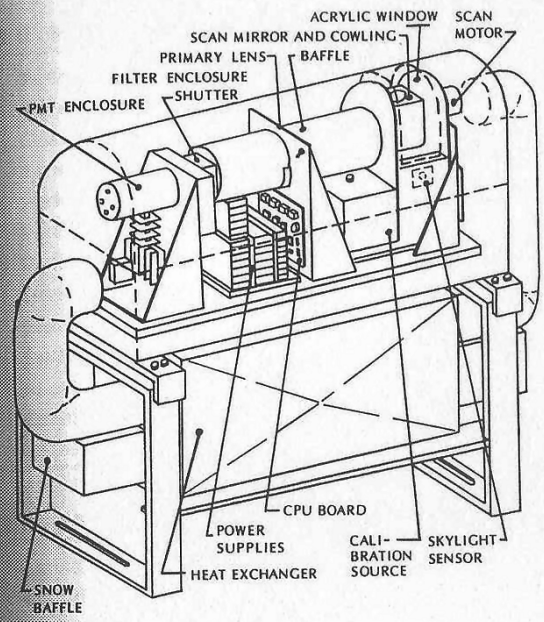

Fig. 1. MSP layout.

during repetitive 30 s scans. Three wavelengths are background channels; the other four correspond to auroral emission wavelengths. The measurements are transmitted in a formatted data stream directly to a local data port, from which they can be stored on magnetic tape. The data are also averaged by "binning" into angular sectors corresponding to 0.5° wide geomagnetic latitudes, corrected for nonlinearity, background, and dark count and then transmitted via satellite link to a central computer. Two of the MSP channels, corresponding to red auroral emission at higher altitude and a background wavelength, are binned into 1.0° intervals.

Internal calibrations and dark count measurements are made once per hour (sandwiched into the 1.5 s of each scan spent at the nadir position) and are reported along with the intensity data.

Communication is normally one-way: the MSP decides autonomously whether or not to scan and sends data and status information to the central computer of the instrument network. A hand-held terminal, however, can be used locally to request special functions or status updates.

The instrument performs scans at night when the sky and local environment are dark and also after all systems have been verified as operating correctly. Temperatures, voltages, light intensities, and local time are monitored and used to control the status of a shutter, heaters, coolers, and fans.

2.2. Optomechanical design

The layout of the instrument enclosure is shown in Fig. 1. The optical design, which provides a solid angle times collecting area product of 0.3 $cm^2 \cdot sr$, consists of an entrance aperture and plane scan mirror, an f/3 primary lens that focuses an image of the sky onto a field stop, an aspheric secondary lens that focuses an image of the entrance stop onto the detector, and a filter wheel located immediately in front of the field stop.

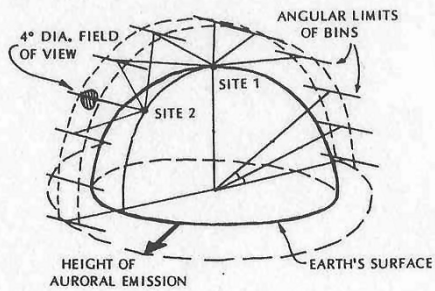

Fig. 2. Observing geometry.

The entrance aperture of the optics is mounted along with the scan mirror in a rotating cowling. The cowling acts as both support and baffle and incorporates a mechanical horizon reference sensed by an optocoupler. The assembly is rotated by a stepping motor (0.225° steps) at a variable rate to attain a nearly constant averaging time for different geomagnetic latitudes, as illustrated in Fig. 2. The stepping motor can be commanded by software to follow a variable-speed scan or to rotate to a particular step (i.e., angle). The scan mirror is as thin as possible to reduce inertia and is cemented to a shimmed aluminum support plate.

An internal calibrator, consisting of an incandescent lamp, absorption filters, and opal glass screen, is mounted at the nadir position of the scan. The lamp is supplied with at most 80% of rated power and is gradually ramped on and off to ensure long life. The lamp and calibrator filter are chosen to simulate the midrange auroral intensities typically measured by each channel.

The combination of scan mirror and simple plano-convex primary lens yields a 1 mm diam image at the 25 mm diam field stop when a point source is viewed.

The filter wheel is rotated at 1200 RPM by an ac synchronous motor. The eight filters are of triple-cavity bandpass type.

Immediately in front of the filter wheel, an electromagnetic shutter controls the transmission of light to the detector. It is commanded to close under bright light conditions and during dark count measurements. The shutter incorporates an optical sensor to verify the position of its blades; its status is reported in the housekeeping information. The aspheric field lens ensures that all light entering the instrument falls on the detector, a 16-stage photomultiplier tube (PMT) operated in pulse-counting mode.

The MSP enclosure can be dismounted from a fixed base permanently mounted on the building roof. The base is initially aligned with the aid of a sighting telescope and levels mounted on one corner. The MSP components are rigidly mounted on an optical bench inside the insulated enclosure. The subenclosures housing the filter wheel and detector assembly are designed to allow the components to be easily removed for transport. The supports for the subenclosures, lenses, and other components are adjustable for optical alignment and allow unimpeded access to devices mounted low in the enclosure.

2.3. Control hardware

The control of the MSP is separated into two hierarchical and physical levels, as diagrammed in Fig. 3. The master

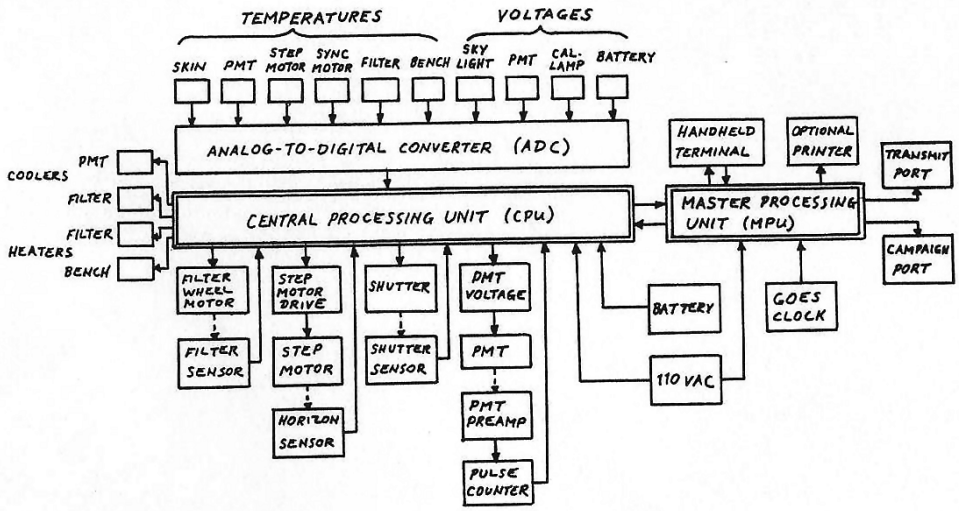

Fig. 3. MSP functional block diagram.

processing unit (MPU) performs the higher-level functions such as setting the operational mode, sequencing scans, and formatting data. The central processing unit (CPU) performs the basic control functions such as temperature regulation, detailed scan management, and monitoring and control of individual components. For example, the scan mirror steps are synchronized with filter wheel rotations via the CPU, which sends the PMT signal and other data to the MPU as 16-bit words. The CPU is located in the insulated MSP enclosure mounted on the roof of the site building. The MPU is rack-mounted in the building below. The MPU and CPU are linked by a signal cable and a power cable supplying ac and battery back-up power.

The MPU, an Intel iSBC86 computer with associated electronics, receives time and 1 Hz references from a Geostationary Operational Environmental Satellite (GOES) clock. It sends all of the data to a campaign port. A transmitter port is used to send averaged, formatted data to a satellite transmitter.

Because the instrument is usually operated far from technical aid, it must control itself, report its condition, and, in the worst case, fail without damaging other subsystems. Table I lists the protection systems employed.

TABLE I. Protection systems of the CANOPUS MSP.

Condition	MSP action	Status communicated
On-axis light too bright	Closes shutter; turns off PMT	Off-axis sensor alarm, shutter closure, and PMT voltage
Sky light too bright	Closes shutter; turns off PMT; switches to IDLE mode	Sky light sensor signal, shutter closure, PMT voltage, and mode
Filter wheel too slow	CPU awaits proper speed	Filter wheel period
Instrument too hot	Switches to IDLE	IDLE mode, zone temperatures, status of heaters and coolers
Instrument too cold	If motors $<0\,°C$, switches to IDLE	Zone temperatures, mode, and status of heaters and coolers
Daytime	CPU rotates scan mirror to nadir and turns off motors and PMT	IDLE mode
Nonrotating scan mirror	Switches to IDLE	Scan alarm bit
GOES clock fault	Switches to IDLE	GOES alarm bit
Power failure	Battery supplies power to filters, if needed.	

2.4. Software

CPU firmware is written in 8086 assembler language. It can be commanded by an instruction set of 15 commands listed in Table II.

The status data include six zone temperatures; voltages of the detector, calibration lamp, and batteries; detector signal and dark count; and status of shutter, light sensors, heaters, and coolers.

The MPU orders sequences of CPU commands based on time of day, status information, and error checking, as listed in Table III. It verifies the quality of satellite clock signals, CPU communication, motor temperatures, filter wheel speed, and sufficient darkness before ordering scans. During daylight hours, or in the event of any error, the MSP remains in IDLE mode, during which only status information is transmitted.

The MPU program, written principally in PASCAL, operates with a combination of round-robin scheduling (i.e., an endless loop of sequentially executed routines that are performed when decisional flags are set) and interrupts for the time-critical communication functions.

The instrument is customized for each site by constants stored in read-only memory for latitude/longitude, site name, scan velocity profile, detector nonlinearity, and transmission times.

TABLE II. Software functions of CPU.

1	Perform 1 scan
2	Transmit status data
3,4	Open/close shutter
5,6	Turn calibrator on/off
7	Perform calibration
8	Perform dark count
9	Position mirror to step x
10	Transmit data for specific filter combination for x samples
11	Switch to DUTY mode
12	Switch to IDLE mode
13	Abort active command
14	Reset CPU
15	Initialize MSP

TABLE III. Software functions of MPU.

1	Calculate local dawn/dusk for present date
2	Set MSP mode depending on time and conditions
3	Order scans at 0 and 30 s
4	Correct and format data
5	Send unaveraged data to campaign port after every scan
6	Send averaged data to transmitter port every 2 min
7	Order calibration at 30 s
8	Order dark count at 30 min 30 s
9	Monitor GOES clock time signal
10	Monitor all instrument sensors and order protective action if needed
11	Send status data to optional printer and/or terminal
12	Communicate with hand-held terminal

2.5. Environmental design

The requirement of unattended operation in all seasons demands versatile thermal control. Temperatures at arctic sites can range from −55 °C to more than +30 °C with 100% relative humidity. The MSP must also withstand 125 km/h winds, snow drifts, and solar heating.

Various zones of the instrument are individually temperature controlled. The optical filters are maintained at 20 ± 5 °C; the photomultiplier tube is kept below ambient temperature to reduce thermal noise; the external window of the instrument is heated to 20 °C so that snow or water is gradually cleared; and the rest of the enclosure is controlled between 5 °C and 45 °C to ensure safe operation of the electronics. A combination of insulated subenclosures, thermoelectric coolers, and adhesive foil resistance heaters are employed by the CPU to maintain satisfactory temperatures. Thermostats are used for fail-safe operation of the enclosure heaters and fans.

The thermoelectric coolers, power supplies, stepping motor, and other devices generate some 400 W of waste heat, which is dissipated within the insulated enclosure. Small fans, thermostatically controlled, are used for direct cooling of motors and thermoelectric heat sinks. At ambient temperatures above −10 °C, this power must be removed to avoid overheating. A commercial heat exchanger (VanEE Systems, Saskatoon, Canada) is employed to transfer heat from the air of the sealed enclosure to the cooler outside air.

TABLE IV. Optical characteristics of the CANOPUS meridian scanning photometer channels.

Channel No.	Wavelength Å	Passband (FWHM)	Sensitivity (counts/Rayleigh)
1	6250 (background)	22	0.42
2	6300	22	0.61
3	4800 (background)	22	1.7
4	4857	22	1.6
5	4857	22	1.7
6	4935 (background)	25	1.5
7	4706	25	1.9
8	5577	22	0.11

The enclosure is sealed by gaskets at all joints. The exchanger is situated below the enclosure, and both are mounted above ground level to prevent the accumulation of snow. The exchanger air inlet and outlet include baffles to prevent the entry of snow into the internal ductwork, where it could freeze and block airflow.

To reduce the absorption of sunlight, the instrument exterior is painted white. During the day the scan mirror rotates to the nadir position to expose the reflective rear surface of the cowling to the external window.

3. CALIBRATION

The characteristics of the photomultiplier, photomultiplier preamplifier, bandpass filters, and internal calibrator brightness can vary somewhat from unit to unit and so must be calibrated to relate the MSP response to sky brightness.

After alignment of the scan plane and telescope axis, the instrumental field of view is verified by scanning a fixed external point source. The relative spectral responses of the instrument channels are measured using an external monochromator. The absolute response and the nonlinearity of the detector and counting circuits are determined using an external calibration source having a number of known intensities. This external source of spectral irradiance is traceable to international standards. A four-segment quadratic polynomial is then programmed to correct the MSP response.

In regular operation, hourly automatic measurements of the internal calibration source ensure that drifts in sensitivity caused by temperature change or aging of components are noted. Stability of ±5% per night and absolute accuracy of 30% are achieved.

4. PERFORMANCE

Typical sensitivities are listed in Table IV. Channel 8 (5577 Å) is intentionally less sensitive by a factor of about 10 because of the intense green auroral emission at this wavelength.

Figure 4 shows the typical response. The maximum PMT pulse counting rate after linearization is about 12 MHz.

The prototype instrument has been tested between temperatures of −55 °C and +40 °C and operated successfully for more than a year at Gillam (Manitoba). Three more instruments have recently been installed at Rankin Inlet (Northwest Territories), Pinawa (Manitoba), and Fort Smith (Northwest Territories).

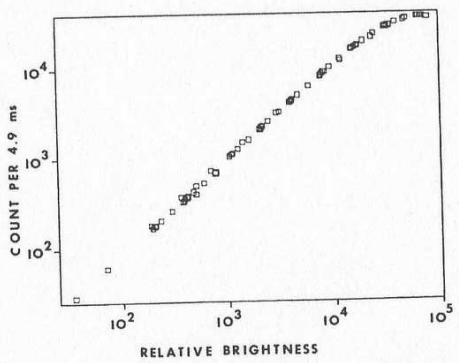

Fig. 4. Relative response. Sampling "window" is 4.9 ms.

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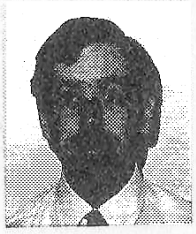
6. REFERENCES

1. A. Vallance Jones, R. L. Gattinger, F. Creutzberg, R. W. King, P. Prikryl, L. L. Cogger, D. J. McEwen, F. R. Harris, C. D. Anger, J. S. Murphee, and R. A. Koehler, "A comparison of CANOPUS ground optical data with images from the Viking UV camera," Geophys. Res. Lett. 14, 391 (1987).
2. R. S. Eather and R. S. Reasoner, "Spectrophotometry of faint light sources with a tilting-filter photometer," Appl. Opt. 8, 227 (1969).
3. G. J. Romick, "The detection and study of the visible spectrum of the aurora and airglow," in *Methods for Atmospheric Radiometry,* D. P. McNutt, ed., Proc. SPIE 91, 63–70 (1976).
4. F. Creutzberg, R. L. Gattinger, F. R. Harris, and A. Vallance Jones, "Pulsating auroras in relation to proton and electron auroras," Can. J. Phys. 59, 1124 (1981).
5. A. Vallance Jones, F. Creutzberg, R. L. Gattinger, and F. R. Harris, "Auroral studies with a chain of meridian-scanning photometers I. Observations of proton and electron aurora in magnetospheric substorms," J. Geophys. Res. 87, 4489 (1982).



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