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Power supply system construction and power monitoring analysis for the dark matter search experiment DIMS.

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The DIMS (Dark Matter and Interstellar Meteoroid Study) experiment was designed to search for the nuclearite, a dark matter candidate, and to observe meteors of extra-solar origin. The DIMS detector with a high-sensitivity CMOS camera had been deployed at the Telescope Array (TA) experiment sites, Black Rock Mesa (BRM) and TARA, in Utah, USA. We are also planning to deploy the detector at the TA Central Laser Facility (CLF) site. Since AC power is not available at the CLF site, solar power is requited to supply power to the instruments. Therefore, it is necessary to design a power supply system using a solar power generation. Remote control of the instruments is also necessary because this experiment will be conducted in the USA. Therefore, we will design and test a power supply system using photovoltaic power generation, introduce a power monitor, analyze it, and remotely control observation equipment. We installed the power supply system at the Nagano Campus of Shinshu University for a long-term test. In this paper, we will report details of the remote operation and the power supply systems to be installed at the TA CLF site, and some results of a long-term test of this system.

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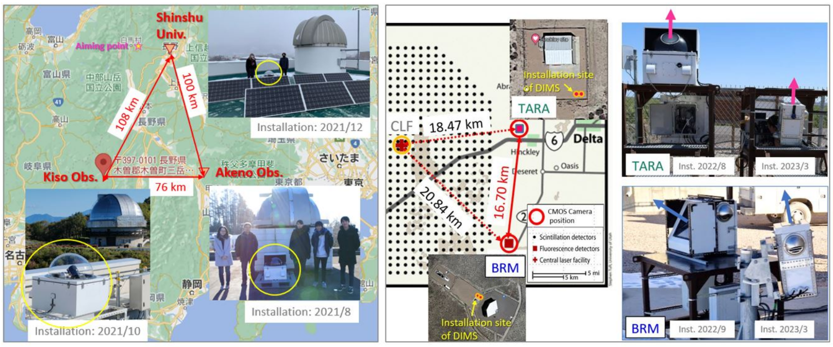
1. Introduction

The DIMS (Dark Matter and Interstellar Meteoroid Study) experiment was designed to search for nuclearites, one of the dark matter candidate, and to observe meteors of extra-solar origin. There is a strange quark matter which consists of roughly equal numbers of up quarks, down quarks, and strange quarks. The nuclearite is a nuggets of the strange quark matter that is thought to be almost electrically neutralized by being covered with electrons. The nuclearite is thought to be produced in the early universe or by collisions between neutron stars, and their sizes range from about the size of an atomic nucleus to the size of a neutron star. Also it is thought that the nuclearite can be observed when it passes through the atmosphere at high speed, elastic scattering or quasi-elastically scattering with molecules and atoms in the atmosphere, causing the atmosphere to become hot and emit light. In the DIMS experiment, the luminescence emitted by the nuclearite as it flies is designed to be observed with a high-sensitivity CMOS camera[5].

The observation instruments are originally scheduled to be installed at 3 locations in the Telescope Array(TA) experimental sites; Central Laser Facility(CLF), Black Rock Mesa (BRM) and TARA, in Utah, USA[3]. Owing to the influence of the COVID-19, we deployed 3 instruments at the central area in Japan at Akeno Observatory, Kiso Observatory and Shinshu University at the first stage. Then, we deployed 2 instruments each at TARA and BRM at the second stage [1, 2]. Figure 1 shows the observation location and observation instruments at the TA experimental site in Utah, USA and those at central area in Japan.



(a) (b)

Figure 1: Observation location and instruments at the central area in Japan (a) and at the TA experimental site in Utah, USA (b). The circled areas in the image (a) show the observation equipment installed.

Observation equipment requires remote control and a stable power supply. For example, the observation equipment is equipped with Wake On LAN, which is a function to turn on the power of a computer installed in a remote location via a network, and a relay circuit in case of malfunction. Therefore, the power supply can be activated even in a remote location. Since AC power cannot be used at the planned installation site, CLF, solar power will be used to supply power to the observation equipment[4]. Therefore, it is necessary to design a power supply system using photovoltaic power generation. In this research, we will design and test a power self-sufficiency system using photovoltaic power generation, introduce a power monitor, and verify its stability. An operational test of the electric power supply system is being conducted at the Nagano campus of Shinshu University, to which we hereafter refer asShinshu University. Figure 2 shows the observation equipment installed on the roof of a building at Shinshu University.

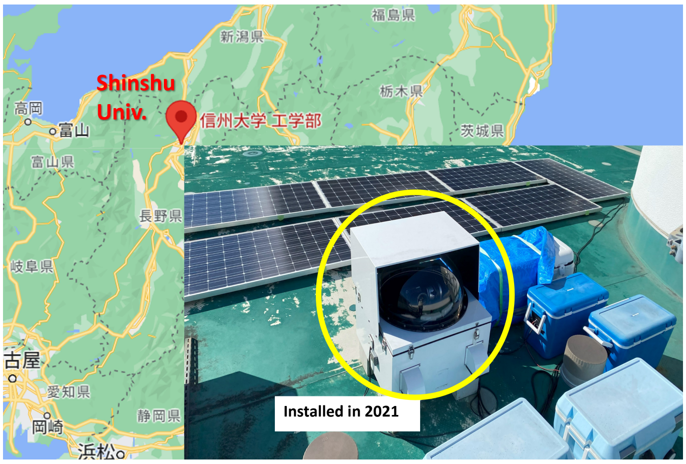


Figure 2: Observation equipment installed on the roof of a building at Shinshu University. Circled are the observation devices that have been installed.

This paper introduces the design and test results of the power self-sufficiency system for the observation equipment using photovoltaic power generation, which is planned to be installed at the CLF, and the details of the introduction and analysis results of the power monitor.

2. Power Supply System

In this research, we developed a power supply system using photovoltaic power generation for the observation equipment[4]. Figure 3 shows a block diagram of the Power Supply System.

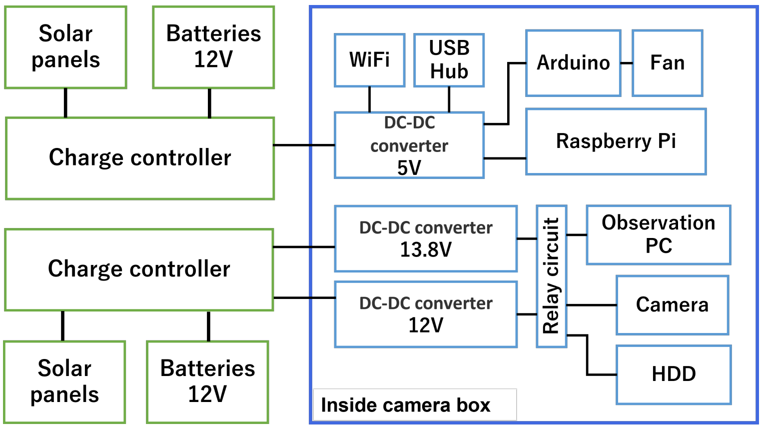


Figure 3: Block diagram of the electric Power Supply System

Table 1 lists the main observation devices in the camera box and their power consumption. The total power consumption of the main observation equipment is 126.5 W. The device needs to operate for 16 hours during observable nights. Power is supplied by a battery. Therefore, the battery needs to be charged during the day. It is desirable to be able to observe for several days even if charging is not possible due to bad weather.

Table 1: Main observation devices in the camera box and their power consumption

Equipment	Number of units	Allowable voltage[V]	Power consumption[W]
Observation PC	1	12 – 24	65
HDD	1	12	36
Camera	1	11 – 17	12
Raspberry Pi 3 Model B	1	5	6.5
Arduino Uno R3	1	6 – 20	4.5
Fan	1	4.5 – 13.8	2.5
Total			126.5

2.1 Design of power supply systems

It is necessary to design the power supply system so that the observation equipment can operate stably during observation. Power for the observation PC is supplied using a DC/DC converter. A DC/DC converter is a control device that raises or lowers a DC voltage. Figure 4 shows a wiring diagram of the power supply for the observation PC.

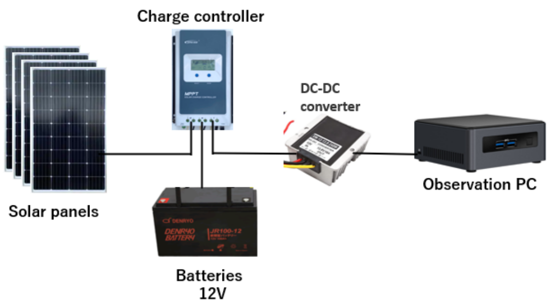


Figure 4: Wiring diagram of power supply for observation PC

Especially important is the minimum operating power of the observation PC, and we measured the lower limit of power at which the observation PC can operate stably using a regulated DC power supply. Table 2 shows the measurement results of the lower limit of power at which the observation PC can operate stably.

Table 2: Measurement results of the lower limit of power for the observation PC

Voltage[V]	Startup current[A]	CPU under load[A]	Maximum power consumption[W]	State
18	2.6	2.0 – 2.3	46.8	OK
16	2.9	2.3 – 2.5	46.4	OK
14	3.2	2.6 – 3.0	44.8	OK
12	3.9	3.1 – 3.6	46.8	OK
11	4.2	-	46.2	NG

The lower limit for stable operation of the observation PC was found to be 46.8 W at 12 V and 3.9 A. I installed a DC/DC converter (output 13.8 V, 18 A) that can supply power to stably operate the observation PC, and conducted a one-day operation test under the same conditions as the observation. As a result, the observation PC operated stably. It was installed in a camera box at Shinshu University, and an operation test was performed overnight under observation conditions. Figure 5 shows the power monitor of the observation PC when it was installed at Shinshu University and tested overnight under observation conditions. The vertical axis indicates ON/OFF of the observation PC. As a result, we were able to confirm that it was operating well from the start to the end of the test, and we were able to observe without any problems.

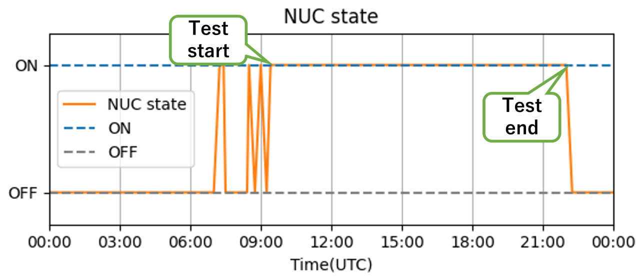


Figure 5: Power monitor for observation PC @ Shinshu University

2.2 Power Monitor

The power supply system must always be monitored for stable operation. Therefore, we developed and introduced automatic power monitors for voltage, current, and power consumption of solar cells, batteries, and loads, as well as battery and internal temperature of the equipment. Figure 6 shows a wiring diagram of the power monitor. Power monitoring is performed by a charge controller that measures the voltage, current, and power consumption of the solar cell, battery, and load, as well as the battery and internal temperature of the device, and is run and recorded every 5 minutes by the Raspberry Pi. Since the power supply system is divided into two systems, power is monitored for a total of two units: the observation PC side where the observation PC, HDD, and camera are connected, and the Raspberry Pi side where the Raspberry Pi, Arduino, and other devices are installed.

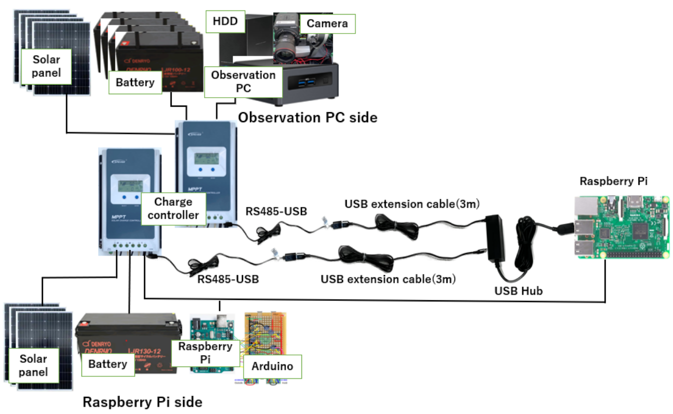


Figure 6: Wiring diagram for power monitor

We installed it in a camera box on the roof of the building at Shinshu University, and conducted an operation test of the power monitor overnight under observation conditions. Figure7 and Figure8 show the graphs of the recorded data of the power monitor on the Raspberry Pi side and the power monitor on the observation PC side.

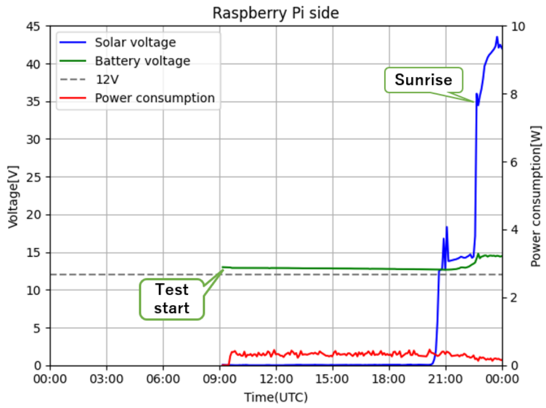


Figure 7: Power monitor on Raspberry Pi side

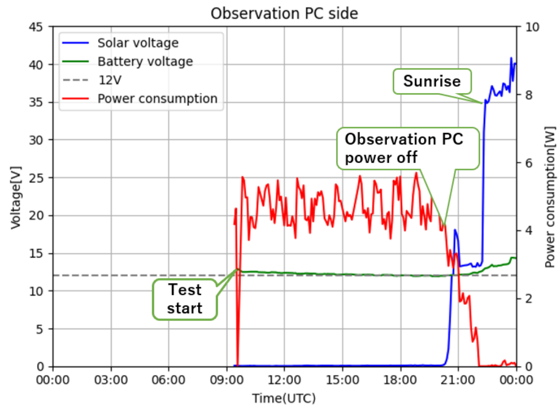


Figure 8: Power monitor on observation PC side

Both batteries had been depleted since the start of the observation, and the voltage was dropping. Also, the solar voltage was rising at sunrise. Furthermore, the power monitor on the observation PC side shows a decrease in power consumption when the observation PC is turned off. The results confirmed that the two power monitors on the Raspberry Pi side and the observation PC side were working properly and that the power supply system was operational.

2.3 Stability of power monitor

We analyzed the power monitor to determine the battery capacity for a stable observation in the following way:

1. Find the probability that the battery is fully charged.
2. Calculate the charging time of the battery with the data of the day when it is fully charged.
3. Find the charging time per battery.
4. Find with what probability the observation PC is stopped.
5. Find how many hours the observation PC has been running, and find the time when the operating time is insufficient.
6. Find the battery capacity that will not stop the observation PC during the observation.

After analyzing the probability that the battery is fully charged, it was found that the probability is 50 %. The following results were obtained by determining the battery charge time with data from days when the battery was fully charged. Table 3 shows the results of the analysis of battery charging times on days when the battery is fully charged.

Table 3: Analysis of battery charge time on days when the battery is fully charged.

Minimum value	175 min
Maximum value	65.0 min
Mode & Median	125 min
Standard deviation	18.9 min
Average	129 min
Charging time per battery	32.3 min

Charging time per battery is the average divided by 4 connected batteries. It was found that each battery was charged in 32.3 minutes. The observation PC is scheduled to operate for up to 970 minutes under observation conditions. The following results were obtained by determining the operating hours of the observation PC. Table 4 shows the results of the analysis of the operating status of the observation PC.

Table 4: Results of analysis of operating status of observation PC

Minimum value	0 min
Maximum value	840 min
Average	706 min
Standard deviation	139 min
Median	735 min
Mode	840 min
Observation PC operating shortage time	130 min

Observation PC operating shortage time is the time obtained by subtracting the mode of 840 minutes from the expected operating time of the observation PC of 970 minutes. It turned out that the observation PC has been operating for 840 minutes, which is 130 minutes less than the scheduled operating time. The battery capacity installed on the observation PC side is 430 Ah. In addition, the PC for observation has an operating time of 840 minutes and an underutilization time of 130 minutes.

The current consumption per hour is $430\,[\mathrm{Ah}] \div 840\,[\mathrm{min}]/60\,[\mathrm{min/h}] = 30.7\,[\mathrm{A}]$ The battery capacity for the lack of operation time of the observation PC is $30.7\,[\mathrm{A}] \times 130\,[\mathrm{min}]/60\,[\mathrm{min/h}] = 66.5\,[\mathrm{Ah}]$ As a result, it can be expected that the observation PC will not stop during observation by increasing the battery capacity by 66.5Ah.

3. Conclusion

The DIMS (Dark Matter and Interstellar Meteoroid Study) experiment was designed to search for the nuclearite, one of the dark matter candidates, and to observe meteors originating outside the solar system. Since commercial AC power cannot be used at the planned installation site, CLF, we developed a power supply system using photovoltaic power generation for the observation equipment. Operation test and observation test of observation equipment were conducted at the Nagano Campus of Shinshu University. As a result of the test, the power supply system operated stably and was able to be observed without problems. In addition, a power monitor was developed to confirm that the power supply system is always operating stably. As a result of analyzing the power monitor, the stability of the power monitor could be verified.

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