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Solar Power Supply and Environmental Control System for DIMS Experiment

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The DIMS (Dark matter and Interstellar Meteoroid Study) experiment is aimed at searching for macroscopic dark matter such as nuclearites and SQM (strange quark matter) and observing interstellar meteoroids. The DIMS experiment system is under construction at the CLF, BRM, and TARA sites of the Telescope Array cosmic-ray experiment facility in Utah, USA. The DIMS experiment system consists of four high-sensitivity camera modules, each of which will be installed at sites about 20 km apart.
Since there is no power supply from the power company at the CLF site, a self-sufficient power supply system is required. Therefore, we developed a new solar power generation system and performed an experiment in Japan first.
Since the DIMS experiment system needs to run stably every night for a long period of time, it is necessary to monitor and control the environmental parameters such as temperature and humidity in the camera module at each site. Therefore, we have developed an environmental monitoring and control system for the camera module.
In this paper, we report on the development and test results of the solar power generation system, which provides self-sufficient electricity for this experiment, and the environmental monitoring and control system for the camera modules.

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1. Introduction

In the standard model of cosmology, the total mass–energy of the universe is thought to contain ~5% ordinary matter, ~27% dark matter (DM) and ~68% dark energy (DE) [1] [2]. Therefore, DM constitutes ~80%[a] of total mass, while a sum of DM and DE constitutes ~95% of total mass–energy content. Well considered and searched for DM so far are new particles that are not part of the standard model of particle physics, such as Weakly Interacting Massive Particles (WIMPs) and axions. More recently, there has been renewed interest in primordial black holes and macroscopic composite objects (called macros), especially those of about nuclear density such as Strange Quark Matters (SQM). The theoretical study of SQM was originally derived from Witten's work [3], which was followed by De Rujula et al.'s proposal for experiments to detect electron-captured SQM, called 'nuclearite'[4]. Many theoretical studies and exploratory experiments have been devoted to DM, however, in spite of its importance, it has not yet been discovered.

The motion of the solar system through the Local Interstellar Cloud (LIC) leads to the presence of interstellar particles [5]. This is also the case when meteoroids ejected from other solar systems enter the solar system. To date, the LIC is the only confirmed source of interstellar particles that were measured by dust detectors, mainly on board the Ulysses and Galileo spacecraft [6] [7]. The existence of interstellar meteoroids measured so far by ground-based instruments has been questioned due to the difficulties of the measurements [8] .

The DIMS experiment aims to observe a candidate of DM and interstellar meteoroids using an array of high-sensitivity CMOS camera modules [9]. Four camera modules will be installed at the first stage at the CLF, BRM and TARA site of the Telescope Array (TA) cosmic-ray experiment facility in Utah, USA. The sites are located about 20 km away from each other (Fig. 1).

Since there is no power supply from the power company at the CLF site, a self-sufficient power supply system is required. Therefore, we developed a new solar power supply system and performed a test experiment in Japan first.

Since the DIMS experiment system needs to operate stably for a long time every night in the extremely severe environment of the Utah desert, it is necessary to monitor and control environmental parameters such as temperature and humidity in the camera module at each site. Therefore, we have developed an environmental monitoring and control system for the camera modules.

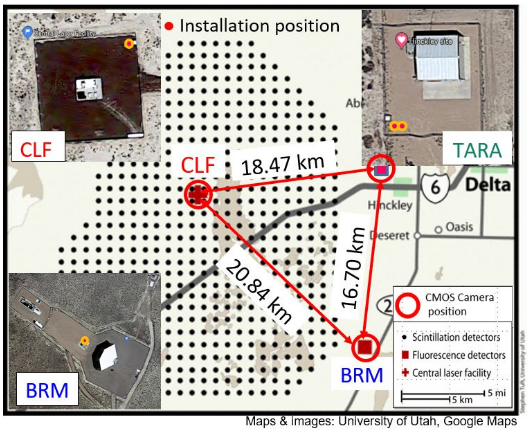

Figure 1: Observation site at TA in Utah. Camera modules will be installed at red marked positions.The solar power supply system is used at CLF.

In this paper, we describe the development and test results of a solar power generation system that provides self-sufficient electricity for this experiment, and an environmental monitoring and control system for the camera module.

2. DIMS Experiment System

A block diagram of a system in each camera module of the DIMS Experiment with a solar power supply system is shown in Fig. 2.

Video images are taken by the high-sensitivity camera at a frame rate of 29.97 fps or 59.94 fps with a pixel resolution of 1920×1080 and their HDMI signals are sent to a PC through an image capture device. Tracks in each image are triggered by a software and their video images are stored in an SSD device in the PC.

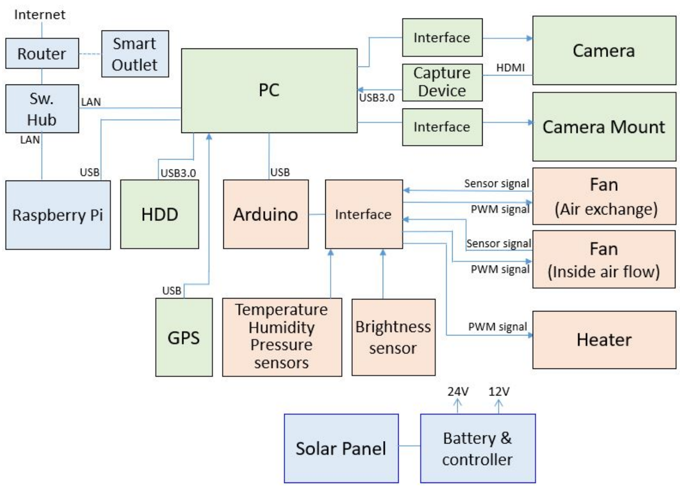

Figure 2: DIMS camera module system and the solar power supply system.

An Arduino microcontroller reads ambient temperatures, relative humidities, atmospheric pressures inside and outside the camera box and controls 2 fans and a heater to stabilize the temperature and humidity inside the box. The camera systems are controlled remotely through the Internet by using TeamViewer remote access and control software.

The solar power supply system provides 24 V and 12 V to many equipment of the camera system.

3. Environmental Monitor and Control System

Even though the operating temperature range of the experimental equipment in the camera module such as the high-sensitivity camera and PC is 0-40°C, the temperature during the observation at the experimental site may exceed that range. In addition, when the temperature drops in the morning, condensation may cause fogging of the acrylic dome or camera lenses. Therefore, we need to monitor the temperature and humidity constantly and control them so that they do not interfere with the observations.

Two BME280 sensors [10], one inside the camera box and one outside, acquire temperature, relative humidity (RH), and atmospheric pressure data, which are read by an Arduino microprocessor that drives a fan that exchanges air between the inside and outside of the box and an air circulation fan inside the box. The BME280 sensor has a temperature accuracy of ±1.0 °C (0-65 °C), a humidity accuracy of ±3.0 % (20-80 %RH, 25 °C), and a atmospheric pressure accuracy of ±1.0 hPa (300-1100 hPa, 0-65 °C).

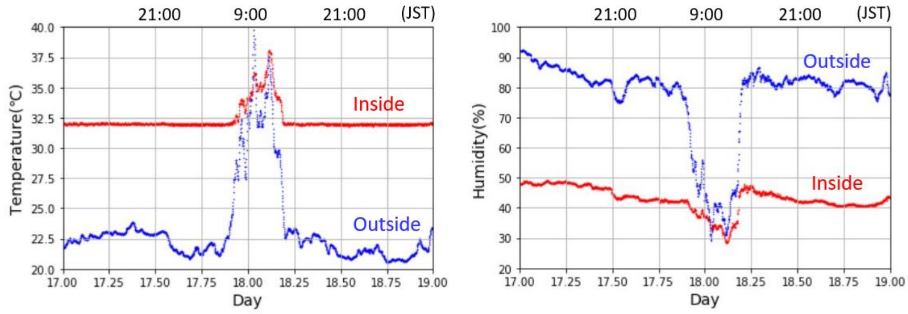

Figure 3: Examples of measured temperature and relative humidity for 2 days.

Examples of measured temperature and relative humidity inside and outside the camera box as a function of days in May, 2021 during 2 days are shown in Fig. 3. The temperature inside the box during these two nights was almost constant, indicating that it was well controlled, while the temperature inside the box could not be controlled to a constant value as the outside temperature rose rapidly during the day. However, this is not a problem since the observation is done at night. Also, while the humidity outside the box was extremely high for two days, the humidity inside the box was kept below 50%. When the humidity on the surface of the material reaches 100%, condensation occurs, but the humidity inside the box is kept low enough.

4. Solar power supply system

We developed a power supply system using solar panels, batteries, and a charge controller to operate the instruments at our experimental site in Utah almost every night for a long period of time. Figure 4 shows a conceptual image of the solar power supply system and the DIMS camera module. The charge controller has two main purposes: one is to optimize the charge from the solar panels to the battery in a solar power system, and the other is to ensure that the electricity stored in the battery does not go through the solar panels when the sun is not shining.

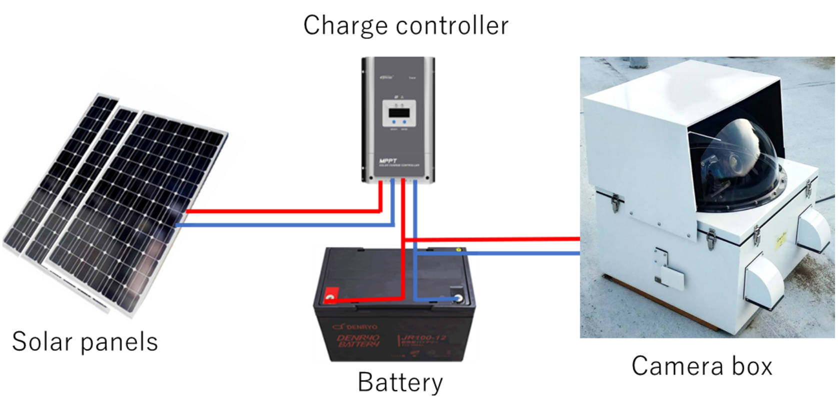

Figure 4: Conceptual image of the power supply system and the DIMS camera module.

4.1 Operation test of the power supply system

A solar power test system was developed on the campus of OECU to measure output voltage changes from a solar panels and two batteries. Figure 5 shows a wiring diagram for the operation test of the solar power supply system and a picture of the test.

For the solar panel, we used Kyocera model KC125TJ, which has specifications of maximum output power of 125W, maximum output operating voltage of 17.4V, and maximum output operating current of 7.2A. For the charge controller, we used a SunSaver model SS-20L with a charge rating of 20 A and nominal battery voltage of 12 V. For the battery, we used a Denryo model Jr100 with an output voltage of 12V and a rated capacity of 100Ah at 10hr rate. In this system, we first used LED lights as loads and measured the voltage changes using voltage loggers.

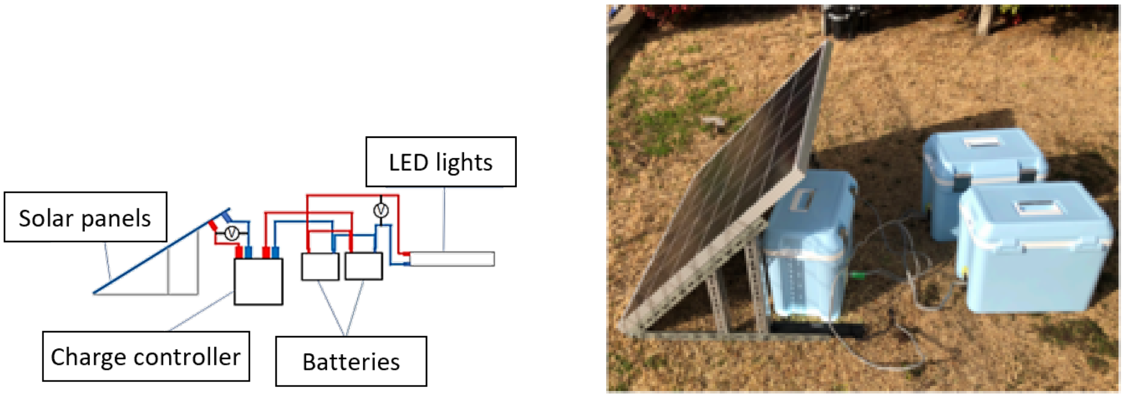

Figure 5: Left : Wiring diagram for the operation test of the solar power supply system.
Right : Picture of the operation test. Two batteries and a charge controller are housed in plastic boxes.

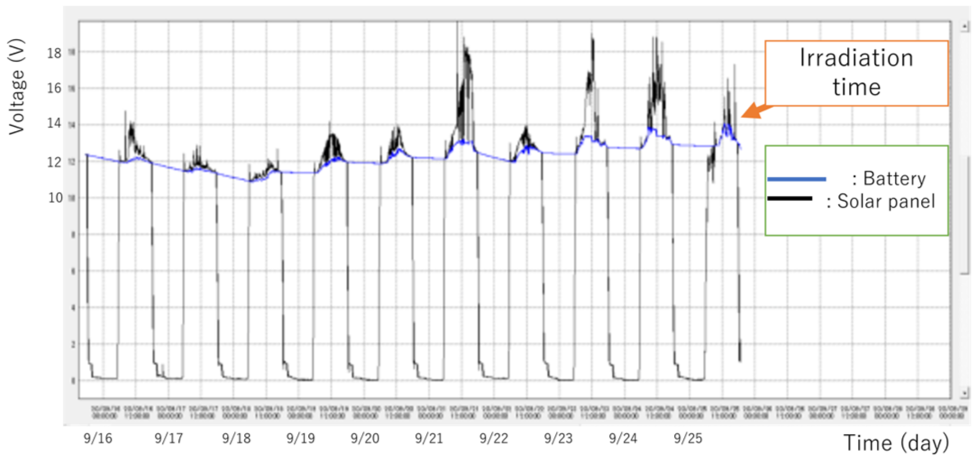

Figure 6: Result of operation test.

Figure 6 shows the measurement results of the output voltages of the solar panel and the battery. The irradiation of the solar panel by sunlight increased the output voltage of the solar panel, which in turn increased the output voltage of the battery. Therefore, it was confirmed that the power system was working properly. In addition, the battery output voltage was found to be within the range of 12V±2V during 10 days of measurement.

4.2 Power calculation and design of power supply system

The solar power supply system to be used at the CLF site (39°17’49"N, 112°54’32"W) is designed to operate without sunlight for three days, and the solar panels are designed to generate enough power to charge the batteries to full capacity in one day. Table 1 shows a list of main observation equipment for the camera module. The total power consumption of these equipment is about 100 W.

Equipment	Voltage tolerance (V)	Power consumption (W)
PC	12 - 24	15
HDD	12 ± unknown	36
Camera	11 - 17	12
Camera mount	11 - 15	12
Arduino Uno R3	6 - 12	4.5
Raspberry Pi 3 Model B	4.75 - 5.25	2.0
Fans	4.5 - 13.8	4.0
Switching hub	5.3 ± unknown	3.3

Table 1: List of main observation equipment for the camera module to be used at the CLF site, Utah.

Assuming a daily observation time of 10 hours and a conversion efficiency of 90 % for the switching power supply, and considering a total power of 63 W for the 24 V power supply system and 47 W for the 12 V power supply system, the required battery capacity becomes 88 Ah for the 24 V system and 131 Ah for the 12 V system.

On the other hand, if we estimate the daily sunshine hours to be 5 hours and the efficiency of the solar panels to be 55% by considering the intensity of solar radiation, power of 687 W is required from the solar panel for the 24 V power system, and 513 W for the 12 V power system. Here, we calculated the power generation based on [12], and the power generation efficiency based on [11].

Based on the above considerations, we decided on the type and number of solar panels and batteries. Figure 7 shows a wiring diagram for the solar power supply system to be used at the CLF site. For the 24 V system, two solar panels are wired in parallel, and two more of these pairs are wired in series, and two 12 V batteries are connected in series to provide 24 V output. The voltage sent to each equipment in the camera module is stepped down from 24 V to 15 V for the camera and PC, and 12 V for the HDD. For the 12 V supply system, three solar panels are connected in parallel and a single battery is used to provide a 12 V output. An Arduino, a switching hub, two fans and a camera mount are operated at 12 V, and only the Raspberry Pi is operated at a step-down voltage of 5 V.

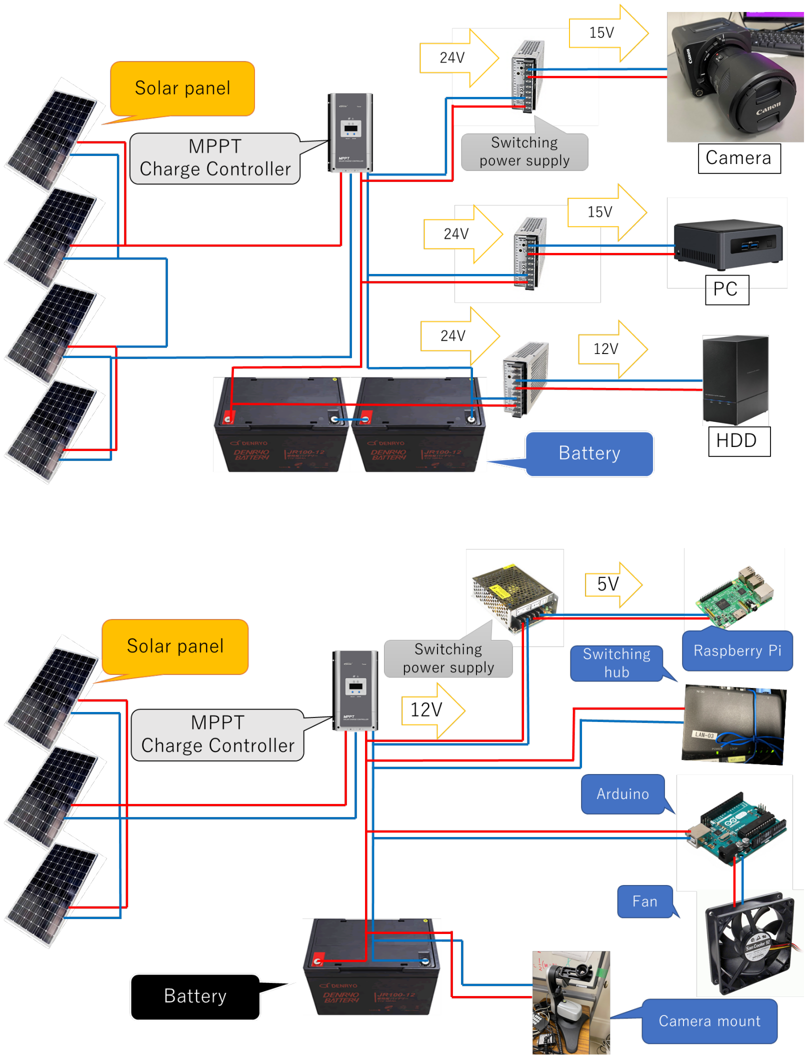

Figure 7: Wiring diagram of the 24 V solar power supply system (top). Wiring diagram of the 12 V solar power supply system (bottom).

5. Conclusion

We developed and tested the solar power supply system, and also the environmental monitoring and control system for the camera modules of the DIMS experiment. We will use a 24 V and 12 V power supply system at the experimental site based on the test results at the university campus. In the design of the power supply system, a safety factor, efficiencies and the amount of electricity generated by the solar panels were taken into consideration. The environmental monitoring and control system was also shown to be functioning as designed.

Acknowledgement

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