Development of Commercial-Off-The-Shelf Imaging Payload for Cloud Coverage Monitoring

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Abstract

Locana Bhumi payload is one of the selected payloads in The 2nd GRSS Student Grand Challenge, and it will be installed in a 3U Cube Satellite. Its main mission is to monitor cloud coverage in several regions such as Indonesia, United Arab Emirates, Oman, and Australia. Clouds have a role in climate change, they are able to reflect infrared light and cool the surface of the earth that is covered by clouds. At the same time, clouds are also able to trap heat, as a result, they warm the earth. By monitoring cloud coverage over the selected areas, it is expected that we will be able to study how cloud coverage could affect the climate system on the earth. In order to monitor the cloud coverage, the Locana payload will capture cloud images by using a small serial camera that is equipped with a low voltage ¼-inch 5-megapixel OV5642 image sensor. This camera also employs a 4.14 mm focal length fixed-infrared-cut-filter lens. This camera is able to capture 500 x 375 km^2 of the area from about 575 km above the earth's surface, with that area observation, the cloud coverage is expected to be easier to observe. In terms of image storage, this payload is integrated with a 1 Gigabit memory. This memory is also used for saving the payload housekeeping data. To prevent the payload from overcurrent situations, the payload system is integrated with an Over Current Protection module. Moreover, an alloy-based enclosure has been designed to protect the component from outer space radiation. The material used for the enclosure is aluminum alloy 7075. The payload has a compact dimension, which fits in 0.5U of Cube Satellite size. Currently, the development of this payload has reached the Critical Design Review stage and it is expected to be ready in Quartal-1 2022.

Keywords

Climate change, cloud coverage, Cube Satellite, RGB camera

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Acronyms/Abbreviations

CDR	*Critical Design Review*
CubeSat	*Cube Satellite*
Gb	*Gigabit*
OCP	*Overcurrent Protection*
PCB	*Printed Circuit Board*
PDR	*Preliminary Design Review*
RGB	*Red Green Blue*

1. Introduction

Climate change is one of the climate systems phenomena that could change the condition of the earth. Climate change can be detected by observing one of the few things, one of them is clouds. Clouds strongly affect the climate system on the earth in many ways. Clouds could warm the earth by trapping some heat in the atmosphere. At the same time, clouds are also able to cool down the earth by radiating infrared light to space [1]. Climate scientists have been studying how clouds could change the daily weather, the seasonal cycle, and even climate system changes from year to year [2]. However, further research and observation are still needed in order to predict the future climate. The satellite with cloud observation mission-related may help the climate scientists to study more about how clouds could change the climate system or even predict future climate by providing the clouds data that are needed.

Locana Bhumi payload is one of three selected remote sensing payloads in The 2nd GRSS Student Grand Challenge developed by a student team from Telkom University, Indonesia. The mission of the Locana Bhumi payload is to monitor cloud coverage in Bandung and North Sumatera in Indonesia, United Arab Emirates, Oman, and New South Wales in Australia. In order to achieve that goal, this payload will take pictures of the clouds that cover those selected areas using a COTS RGB Camera. Previous research regarding the usage of that camera has been done by [3]. The Preliminary design of this research payload has been done [4]. By developing this payload, it is expected that the images taken could be used to study more about how clouds could affect the climate system or even predict future climate.

This research result is an engineering model of a remote sensing payload that employs a Commercial-Off-The-Shelf RGB Camera which is able to capture low and high-resolution images. This camera is controlled by a low-power ARM Cortex M0 microcontroller. A NOR memory is used to store the images. In order to manage the memory allocation, memory management is applied.

2. Payload System

The challenge of this project is to develop a payload that fits into a 3U CubeSat. There are three payloads that will be carried by this 3U CubeSat, therefore each of the payloads should be fit into less than 1U spaces inside the CubeSat. Besides that, the payload should consume the amount of powers as small as possible. The payloads also have to be able to perform from 575 km above the earth.

The mission of the Locana Bhumi payload is to monitor cloud coverage by taking images of clouds from time to time. In order to meet the requirements, the Locana payload uses a mini serial camera that only needs 0.5U CubeSat, a low-power microcontroller unit, and other instruments with only 3.3 Voltage level power consumption respectively.

2.1. Payload Instruments

There are three main instruments that are used in the Locana Bhumi payload, they are RGB Camera, Microcontroller, and Memory.

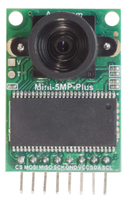

Figure 1. OV5642 RGB Camera [5]

In order to take pictures of clouds, the camera used in the Locana payload is a low-power ¼-inch OV5642 RGB sensor camera module from Arducam. This camera provides resolution options from QVGA to 5MP [5]. Due to the limited size of data that the Locana payload may transfer, the resolutions that will be used are only QVGA to VGA. However, those resolutions have fit the requirement in the cloud imagery case.

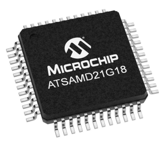

Figure 2. ATSAMD21G18 Microprocessor [6]

The microprocessor used for the microcontroller is a low-power ATSAMD21G18. The microprocessor is integrated with a 32 kHz oscillator and other components to form the 32-bit microcontroller. It has 256 kb of flash memory and 32 kb of RAM [6]. It is chosen because it is compatible with the OV5642 camera, and it has the lowest power consumption compared to other microcontrollers.

Figure 3. MT25QL01GB NOR Flash Memory [7]

The memory used to store the captured images and taken housekeeping data is NOR Flash Memory MT25QL01GB. It has 133 MHz maximum clock frequency, 1 Gb memory size, and uses SPI peripheral [7].

To monitor the health conditions of the payload, this payload also carried an analog temperature sensor LM335D to monitor the temperature around it. To prevent the payload from overcurrent condition, the power lines of the payload are connected to the Over Current Protection LTC4361 module.

2.2. Block Diagram

The integration of all instruments that are used in the Locana Bhumi payload could be seen in figure 4 below.

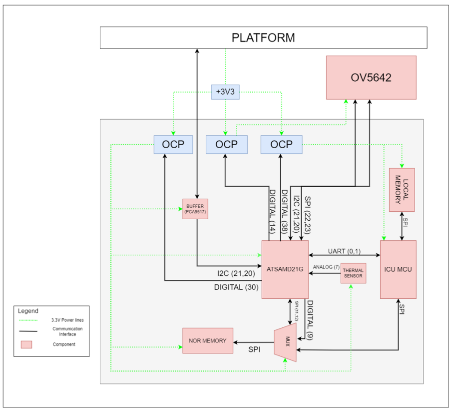

Figure 4. Payload Block Diagram

Locana payload will be given 3.3 Voltage level power from the platform. Before all instruments are supplied, the supply will go to the OCP module to prevent an overcurrent supply that could damage the payload. If there is an overcurrent detected by the OCP, then it will cut the power lines automatically. The OCP also could be used as a controller to turn on or off the load. In this case, it will be controlled by the microcontroller. The power lines between the camera and other instruments are using different OCPs, so when the camera is supposed to be turned off, other instruments are not going to turn off as well.

2.3. Operational Mode

The payload itself has two operational modes, they are mission and calibration mode.

a. Mission Mode
   In this mode, the payload (i.e. the camera) will work for the mission. The used camera will capture the picture of the cloud in certain target areas. The target areas we will use are North Sumatera and Bandung in Indonesia, New South Wales in Australia, Uni Emirates Arab, and Oman.
b. Calibration Mode
   In this calibration mode, the camera will take a picture of Mount Bromo in Indonesia and Alice Spring in Australia. The purpose of this mode is to check the color correction (i.e., radiometric calibration) of the camera and its functionality. The pictures taken in every calibration will be compared from time to time.

3. Payload Design

3.1. Printed Circuit Board

The PCB has a dimension of 89.22 mm x 89.10 mm and consists of four layers. The interface that is used to communicate with other payloads is the UART interface, while to communicate with the onboard computer is using the I^2C interface. Also, the board consists of headers, OCPs, a microcontroller, a sensor, a multiplexer for sharing the connection between payload from top to bottom layers, and a NOR Flash Memory.

Figure 5. Engineering Model Circuit Board

3.2. Mechanical Design

In this section, the mechanical structure of the Locana payload will be explained. The Locana payload mechanical structure consists of a bracket that has several separate parts. These brackets are used to hold overall components in the payload such as cameras and PCB boards.

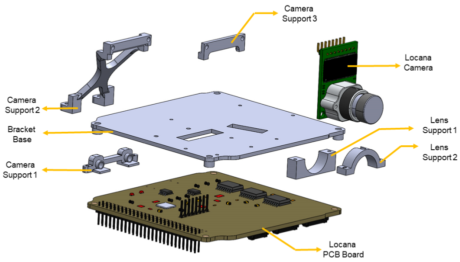

Figure 6. Locana CAD

Brackets are designed with several separate parts for the purpose of simplifying the assembly process so that the supported components can stand firmly. To be able to support the components in order to withstand shocks at the launch stage, the bracket is made of aluminum alloy 7075 with the addition of an anodized layer on the surface.

The selection of 7075 aluminum alloy material is based on the structure of the material that can operate in extreme conditions [8]. On the outer layer of the bracket is given a clear anodize layer to increase high emissivity and low absorptivity that lead to the efficient radiative heat transfer in the space environment [9].

4. Testing and Simulation Result

Several camera testing that should be carried out are RGB quality testing, focus lens testing, and camera endurance testing.

4.1. RGB Quality Testing

To prevent the captured images from infrared light in the atmosphere that could distort the images, the RGB Camera employs an infrared-cut filter lens. Several experiments are needed to make sure this filter lens will not affect the camera in taking RGB colors.

Figure 7. RGB quality testing result

The RGB quality test is done by giving a colorful object, then the RGB camera takes a picture out of it. The sensor of the camera shall differentiate the RGB colors. The picture above is the result of the RGB quality testing. It is shown that the camera could differentiate the RGB colors and produce colorful images well.

4.2. Focus Lens Testing

The Locana Bhumi payload will perform from 575 km above the earth. Therefore, the focus lens of the camera should be set to infinity, so that the camera will be able to capture the clouds as far as possible.

Figure 8. Focus lens testing result using QVGA resolution

Figure 9. Focus lens testing result using VGA resolution

Figure 8 and figure 9 shows the camera is able to take images of clouds clearly with the focus lens set up to infinity.

4.3. RGB Camera Endurance Testing

After the CubeSat is launched, the payload will be operating from month to month, even from year to year, as well as the camera. It is important to make sure the payload, especially the camera, is able to perform for a long time. Therefore, an endurance test needs to be conducted.

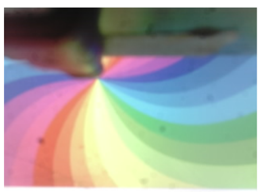

Figure 10. The image was taken right after the camera turns on

Figure 11. The image was taken after the camera turns on for 6 hours

As shown in figure 11, there is color degradation compared to figure 10. Therefore, it is important to turn off the camera before the payload takes pictures to prevent color degradation.

4.4. Memory Management

As mentioned previously, the IC to save the captured images and housekeeping data is NOR Flash Memory MT25QL01GB which has 1 Gb of memory size. Below is the memory management table that mapped the use of the NOR Flash Memory.

Table 1. Memory Management

Allocation	Length (KB)	Start Address	End Address
Image 1	256	0000 0000	0000 3FFF
…	…	…	…
Image 200	256	031C 0000	031F FFFF
Padding	64	0320 0000	0320 FFFF
Internal	64	0321 0000	0321 FFFF
Image Status Data	64	0322 0000	0322 FFFF
Housekeeping Data	64	0323 0000	0323 FFFF
Test Connection NOR	64	0324 0000	0324 FFFF
Camera Setting	64	0325 0000	0325 FFFF

4.5. Mechanical simulation on structure

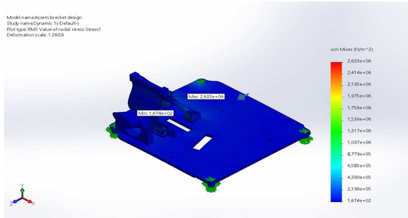

Figure 12. Structure Simulation

We perform a mechanical simulation to determine the toughness of the structure that we have. According to the needs of the space environment, the simulations carried out include random vibration which is carried out vertically and horizontally, and thermal simulations. The simulation results can be seen in Tables 2, Table 3, and Table 4.

Table 2. Horizontal random vibration simulation

Simulation	Type	Min	Max
Stress	Von: von mises stress	1,674e+02 N/m^2	2,633e+06 N/m^2
Displacement	URES: Resultant Displacement	1,000e-24 nm	8,773e+03 nm
Strain	SEDENS: Strain Energy Destiny	7,168e-07 N.m/m^3	4,575e+02 N.m/m^3

Table 3. Vertical random vibration simulation

Simulation	Type	Min	Max
Stress	Von: von mises stress	2,410e+02 N/m^2	9,739e+06 N/m^2
Displacement	URES: Resultant Displacement	1,000e-24 nm	1,683e+04 nm
Strain	SEDENS: Strain Energy Destiny	7,591e-07 N.m/m^3	1,978e+03 N.m/m^3

Table 4. Thermal simulation

Simulation	Type	Min	Max
Thermal	TEMP: Temperature	-3,000e+ ^{O}C	6,500e+01 ^{O}C

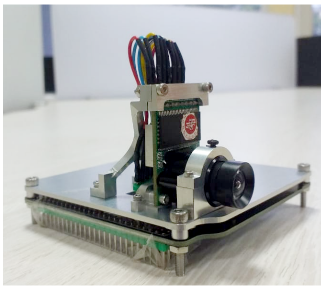

Figure 13. Fitting test result

We have manufactured the engineering model of the structure. As can be seen in figure 13, the payload structure fits the engineering model of the PCB. Based on the result of payload experiments, the result of the mechanical structure simulation, and the CDR, the Locana Bhumi payload is ready to manufacture its flight model.

5. Conclusion

The Locana Bhumi payload engineering model has been developed in this research. Some test to capture images has been done to validate the camera image quality, focus, and its endurance when it is operated for a long time. Based on the experiments that have been carried out, it is proven that a COTS mini serial RGB camera could be used as an instrument for the CubeSat imagery payload. Structure simulation analysis has also been done to check the strength of this payload. In the future, environmental test will be conducted to validate the actual payload vulnerability.

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