CubeSat Electrical Interface Standardization for Faster Delivery and More Mission Success

Mengu Cho, Takashi Yamauchi, Marloun Sejera, Yukihisa Ohtani, Sangkyun Kim, Hirokazu Masui
Kyushu Institute of Technology
1-1 Sensui Tobata-ku Kitakyushu, 804-8550, Japan; +81-93-884-3228
cho@ele.kyutech.ac.jp

ABSTRACT

In 2019, a new project to standardize the CubeSat electrical interface started based on the heritage of the small satellite related standard activities, such as ISO-19683 (testing) and ISO-TS-20991 (requirements). The project aims at registering at new work item at ISO/TC20/SC14 in summer 2021 by summer 2021 and publish the standard by fall 2024. Discussion has been made utilizing various gathering opportunities of the CubeSat community. A survey on the CubeSat interface has been distributed the CubeSat community to collect the satellite developers' experience and desires regarding the interface, and the CubeSat vendors' reality and desires. A research work to identify the difficulties associated integrating CubeSat components from different vendors is on-going. Initial finding suggest that clear definition of interface related information, especially the digital data communication, in the user manual is really needed. A framework of the standard has been drafted, which is mainly made of four parts. (1) Interface among components, (2) Interface between CubeSat bus (platform) and mission payloads, (3) Document specification to describe the information related to component interface, (4)Document specification to describe the information related to CubeSat bus (platform) interface.

1. INTRODUCTION

It has been said that the advantage of CubeSat is low-cost and fast-delivery. Many CubeSat projects, however, are taking longer than two years from the project kick-off to the launch. There are various CubeSat component vendors available worldwide. The electrical interfaces from different vendors are often not compatible, even if they follow PC-104 specification. The incompatibility leads to additional time in the satellite development, assembly and integration. It may even require an interface board or harness to absorb the difference, adding extra complexity to the system. The time spent to solve the interface incompatibility consumes the time to be spent for other verification activities to ensure the mission success. Clear definition of electrical interface, such as the connector type and pin assignment help shortening the satellite delivery time and increase the mission success rate. As CubeSat is now entering the era of mass production, simple interface suitable for mass production is also desired.

The increasing number of CubeSat projects, especially the new-comers, is now buying components from a single vendor. Sometimes, they are buying all the satellite bus components while focusing on development of mission payloads only. CubeSat vendors are also moving toward "platform provider" rather than selling individual components. Considering this recent trend, clear definition of interface between a CubeSat platform and mission payloads is also needed.

In 2019, a new project to standardize the CubeSat electrical interface started with the funding support of Japanese government. The project is led by Kyushu Institute of Technology (Kyutech) based on its heritage of leading the small satellite related standard activities, such as ISO-19683 (testing) and ISO-TS-20991 (requirements). IAA (International Academy of Astonautics) study group, IAA-SG26 CubeSat Interface, started in October 2019 to collect inputs from wider sectors, especially academia, to the standard draft to be submitted by summer 2021. In December 2019, a two-days workshop was held in Tokyo to discuss the issues associated with CubeSat interface more in depth.

As a part of the standardization activities, a survey was distributed to the CubeSat community to collect the satellite developers' experience and desires regarding the interface, and the CubeSat vendors' reality and desires. Also, three PC-104 based commercial components for power, communication and C&DH were acquired from three different vendors to investigate the interface compatibility in detail.

The purpose of the present paper is to provide overview and status of the project, along with the preliminary standard draft to obtain feedbacks from the CubeSat community. The paper is made of six sections. The second section describes the project overview and status. The third section provides the summary of the survey. The fourth section provides the initial findings from integration of PC-104 based components. The fifth section describes the preliminary draft. The six section gives conclusion with future schedule.

2. PROJECT OVERVIEW AND STATUS

The standardization project is partially funded by Japanese Ministry of Economy, Trade and Industry for three years from 2019 to 2021. The goal is to register a new work item proposal at ISO/TC20/SC14 by summer 2021. The project aims at making the first official draft by then. The standard publication is targeted to October 2024.

The motivation of the project originates from the activities during IAA SG4.18, "*IAA Study on Definition and Requirements of Small Satellites Seeking Low-Cost and Fast-Delivery*", which studied the concept of *lean satellite*. Its concept is described in detail in the study group report[1]. In short, a lean satellite is a satellite that utilizes non-traditional, risk-taking development and management approaches with the aim to provide value of some kind to the customer at low-cost and without taking much time to realize the satellite mission. The satellite size is small merely as a result of seeking low-cost and fast-delivery.

The study investigated how fast lean satellites were actually developed and delivered to the launch site. The study showed that majority of the lean satellites investigated took more than two years to deliver. Another study [2] investigated 459 satellites of 1-10kg mass launched since 2003, excluding Spire and Planets. It found that about two-thirds of the satellite developed by private companies were delivered to the launch in less than two years. But, less than 30 % of the satellites developed by university were delivered in two years. There are many reasons for this delay in university satellites. But the poorly defined interface among components was one of the major reasons causing significant delay in the satellite integration phase. Ref.[3] shows that once we start system integration, the number of faults detected jumps up mostly because of interface mismatches.

To accelerate the development time, a good interface is needed. Nowadays, CubeSat components are becoming commodity. We can buy CubeSat components in Internet from various vendors. Most of CubeSat components, which are mostly single PCB (printed-circuit-board) has so-called PC-104 interface. Bouwmesster et al. conducted survey on CubeSat electrical bus interfaces [4]. The survey revealed that more than a half of the CubeSat integrator who used PC-104 style components felt the connector was too big and 17% of the integrator felt that pin-assignments are too flexible.

There are several research works to overcome the issues of PC-104. University of Wurzburg promotes a so-called backplane style that does not use PC-104-like stackable architecture. Instead, all the PCBs are inserted into a backplane vertically. It publishes a standard definition document [5] which provides the pin-assignment of 50-pin connectors. Kyushu Institute of Technology adopted the backplane style in BIRDS project that deployed multiple (3 or 5) 1U CubeSat from International Space Station. In one of BIRDS-3 satellites deployed from ISS in 2019, a complex-programmable-logic-device was implemented on the backplane so that the harness routing can be reconfigured by software[6].

As the trend surrounding CubeSats moves toward mass production era, the demand for well-defined and easy to assemble and integrate interface increases to shorten the assembly and integration time. Using harness in a volume-limited CubeSat not only increases the assembly time but also decreases the reliability. To achieve the harness-free, the electrical interface at connectors has to be defined clearly.

Considering the above mentioned situation, having a standard on CubeSat interface among internal components will bring the following benefits to the CubeSat community,

- Shorten the time required for design, development, assembly, integration and testing
- Promote mass production
- Assure component compatibility leading to promotion of international trade of CubeSat components and international collaboration

In the standardization project, we carry out the following activities,

- Making and revising the standard draft
- Coordinating with ISO/TC20/SC14
- Investigating compatibilities among CubeSat components in the market
- Collecting inputs from the worldwide experts and stakeholders through IAA SG-26
- Organizing international workshops to exchange information and to discuss the standard

As a platform of the activities, the project will utilize the lean satellite community which was formulated in the previous international activities to make ISO-19683 and ISO-20991. A Web page https://lean-sat.org/ is available to exchange information.

In 2019, a series of meetings were held using opportunities where CubeSat experts and stakeholders gather. A side meeting was held during 2019 Small Satellite Conference in Utah. During IAC 2019 at Washington DC, the kick-off meeting of IAA SG4.26 was held. Presentations were done in some of CubeSat related conferences, such as 12th Pico- and Nano-Satellite Workshop in Wurzburg in September and 5th IAA Conference on University Satellite Missions and CubeSat Workshop in Rome in January 2020.

International Workshop on Lean Satellite 2019 (IWLS-2019) was held on December 4 and 5 in Tokyo as the main event. In total 88 people participated, among them 33 came from abroad. In the workshop, the major CubeSat component providers, such as Pumpkin, Cylde Space, ISIS, GomSpace made presentations, in addition to various CubeSat developers, universities and private companies, from all over the world. At the end of the workshop, free discussion was done to discuss the CubeSat interface standard. Also, survey on CubeSat interface was distributed and the answers were collected, of which the detail will be shown in the next section.

Figure 1: IWLS-2019 group photo

In the workshop, it has been known that the CubeSat vendors are now moving to CubeSat platform providers from component vendors while they still sell individual components. The CubeSat developers also now tend to buy components from a single vendor to avoid the interface issues. Considering this recent trend, not only the interface among components, but also the interface between a platform (satellite bus) and mission payloads is important. Also, from the CubeSat developers' point of view, datasheet of each component sold in the market needs to be standardized. Otherwise, the developers suffer interface mismatch after they purchase the components. Based on these findings and discussions, it was agreed that the following four items should be included in the standard

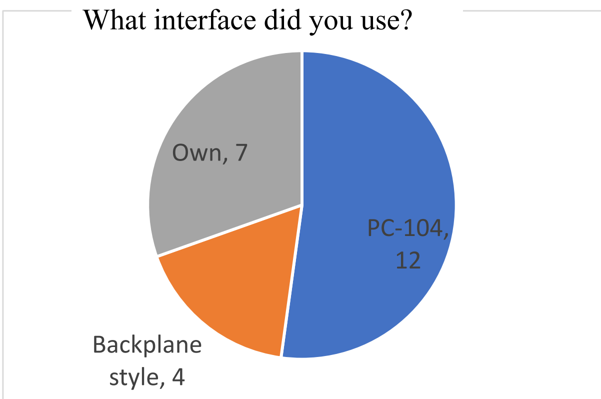
- Interface among components
- Interface between platform (satellite bus) and mission payload
- Document specification to describe the component interface
- Document specification to describe the platform interface

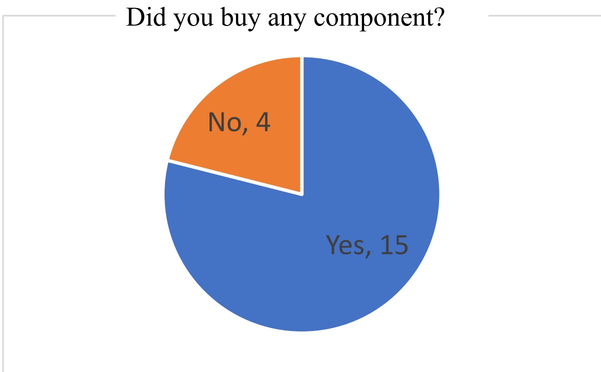
The table of contents of the draft standard is given in Section 5.

3. CUBESAT INTEFACE SURVEY

A survey on CubeSat interface was distributed around the time of IWLS-2019. So far, 50 answers have been collected. They are categorized into 21 CubeSat developers, 9 CubeSat vendors and 20 others. Figure 2 shows how the CubeSat developers integrated their system. Majority used PC-104 type stackable style and more than 3/4 bought the components from the market.

For the question of what components the CubeSat developers bought, many answered that they bought a communication component, which is understandable considering the necessity of good technical skill required for such a component. The next is solar panel, EPS and ADCS. The solar panel and ADCS also require special technical skills. Only one third of the CubeSat developers said that they bought from a single vendor. It may be interesting if we do the same survey three years later as we anticipate more developers will choose a single vendor solution.





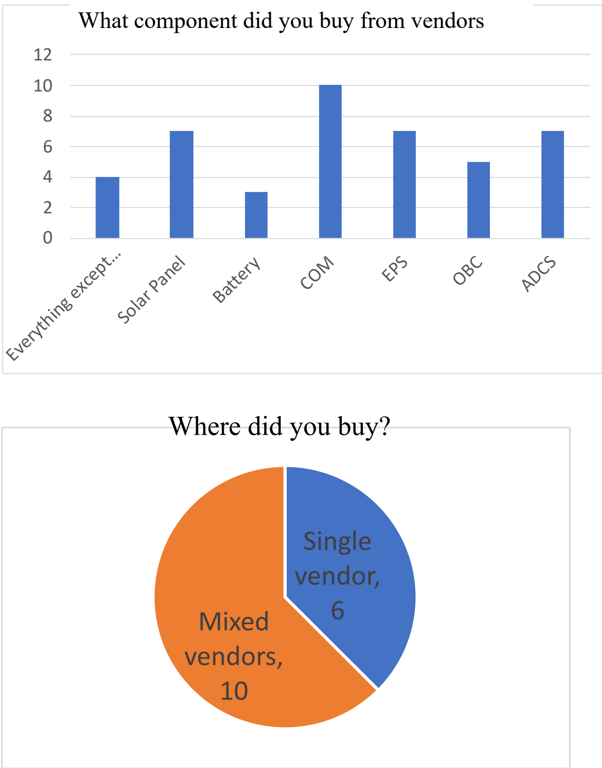


Figure 2: Result of CubeSat Interface Survey (CubeSat developers)

Table 1: Reason of choosing single vendor or multiple vendor solutions (CubeSat developers).

Single vendor solution		Multiple vendor solution	
Not interested in bus development	1	Not possible to buy all components from the same vendor.	3
Avoid interface problems	3	Can provide wider rage of options	1
Bought only one component	2	Price	2
		Depending on requirements and performance, functionality	8

Table 1 shows the answer to the question why the CubeSat developers chose the single vendor solution or the multiple vendor solution. Excluding the two developers who bought only one component, the major reason was to avoid the interface problem. The reason of choosing the multiple vendor solutions is dominated by the answer that the requirement, performance and functionality were the reason.

Table 2: Number of harness lines used in the flight model (CubeSat developers).

No harness except RF cables	1~5	5~10	10~
1	4	6	8

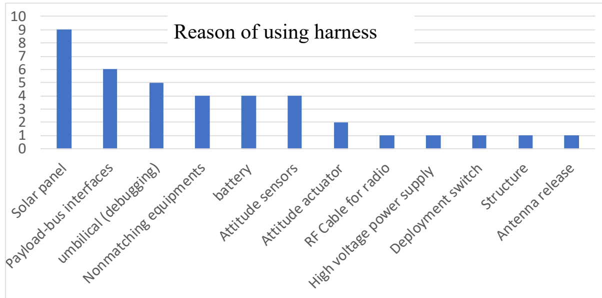
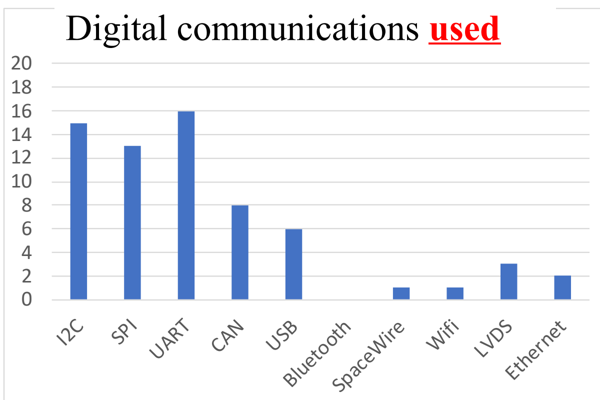


Figure 3: Reason of using harness (CubeSat developers)

Table 2 shows the answer about harness. Many CubeSat developers are still struggling with harness. The main reasons are for external interface, such as connection to solar panel, umbilical for debugging) and attitude sensors. Another reason is the interface incompatibility, where the payload-bus interfaces is also included.

Questions were asked about digital communication inside the satellite. Figure 4 shows the answers by CubeSat developers. The serial communication such as I2C, SPI, UART have been favored until now. But the prediction by the developers indicated that CAN and Ethernet will be favored in future.



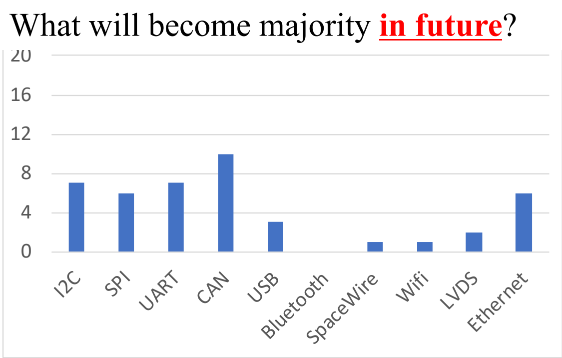


Figure 4: Types of digital communication (CubeSat developers)

Figure 5 shows the answer from the CubeSat vendors. One difference from the CubeSat developers is SpaceWire. Although the vendors have provided SpaceWire, the customer (CubeSat developers) rarely used it. The future prediction also says the same thing. SpaceWire is not favored by the developers as much as favored by the vendors.

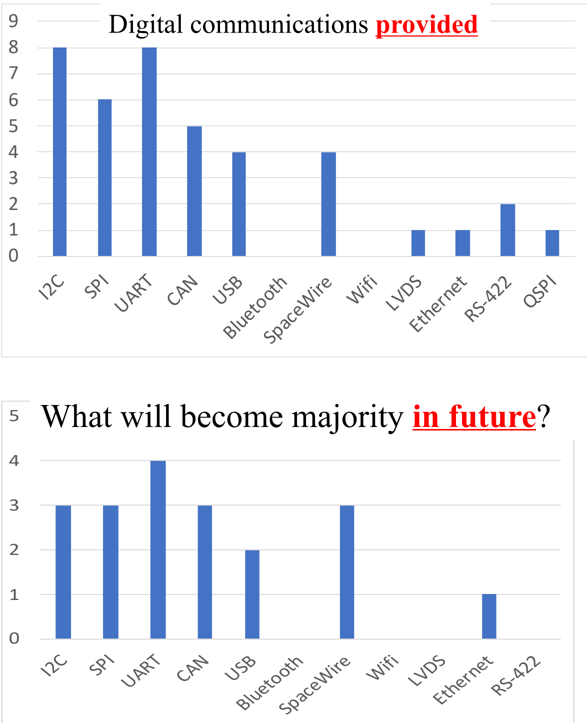


Figure 5: Types of digital communication (CubeSat vendors)

Table3: Answers to how to improve the CubeSat delivery time

In your opinion, what are necessary or need to be improved to accelerate the CubeSat delivery time?	Developers	Vendors
Integration and testing	4	2
Plug & Play to accommodate variety of missions	2	0
Reducing time before first integration.	1	0
Interface	7	3
Close working environment	1	0
Mixture of standard and design pattern	1	0
Improving the information within datasheets	3	0
Improving software and clear software interface	6	1
accelerate administrative overhead (export control by government, frequency allocation, etc.)	3	0
Better quality manufacturing	1	0
More choice of payloads with various combination of functions	1	0
Backplanes easily accessible, easily changed.	1	0
Skill-up of designers	3	0
Dedicated test jig for CubeSat (e.g. vibration)	0	1
Design to manufacturability	0	1
Integration of payload	0	3
Wholesale adoption of Ethernet as the standardized interface	0	1
Selecting an unique bus/component provider	0	1
standardized processes for design and testing,	0	1
improved documentation	0	1

Table 3 shows the compiled answers to the question of asking how to improve the CubeSat delivery time. It is noted that he major bottlenecks in the satellite delivery are, integration and testing, interface and software.

TEST OF PC-104 COMPONENT INTEGRATION

As a part of the standardization activities, we study how really difficult it is to combine CubeSat components from different vendors. We selected an onboard computer (OBC) from ISIS, a UHF transceiver (COM) from Clyde Space and an electrical power system (EPS) with battery from GomSpace. The three subsystems are fundamental subsystem to constitute a CubeSat system bus. All the three components adopt PC-104 style interface. The delivery time was from 3 months to 4.5

months. Considering the processes required for export/import, the delivery time is similar to the case when we buy from Japanese domestic vendors.

Before integrating the three components together, functional testing of individual component were carried out. Even at this stage, there were various problems found. The biggest problems were incorrect or ambiguous information written in the user manuals. Especially, the description of digital data communication such as I2C and the description of data packet format were confusing and led to long debugging time.

The integration test of OBC and COM was done by checking the beacon signal from COM. The COM was programmed to emit a CW beacon signal continuously. Very primitive I2C communication between OBC and COM was possible and the data (temperature sensor data of COM) was sent out as a part of the beacon signal.

The integration between OBC and EPS was very hard. Although a simple functionality such as supplying power was OK, controlling various functionality of EPS via commands from OBC was very difficult. The data transmission via I2C was very difficult due to the issue of the different bit rate and the master-slave relationship.

As of writing the present paper, we are still working on integration of three components. The pin-assignments, especially power pins or I2C signal pins are common. Therefore, we encountered little issue in physically matching the three components. But, the software had a lot of issues. When each component has a processor, coordinating the work among the processors is difficult to do via I2C because of the master-slave relationship.

STANDARD DRAFT

The very first version of the standard draft, "Space Systems – CubeSat Interface" was written reflecting the discussion in IWLS-2019. The outline of the standard draft is following,

FOREWORD
INTRODUCTION
1 SCOPE
2 NORMATIVE REFERENCES
3 TERMS AND DEFINITIONS
4 SYMBOLS (AND ABBREVIATED TERMS)
5 INTERNAL INTERFACE REQUIREMENTS
  5.1 UNIT TO UNIT INTERFACE
    5.1.1 GENERAL
    5.1.2 PC-104 STYLE
    5.1.3 BACKPLANE STYLE
  5.2 MISSION PAYLOAD TO PLATFORM INTERFACE
    5.2.1 MECHANICAL CONNECTION
    5.2.2 CONNECTION METHODS
    5.2.3 GROUND LINES
    5.2.4 POWER
    5.2.5 ANALOGUE DATA INTERFACE
    5.2.6 DIGITAL DATA INTERFACE
    5.2.7 DEBUGGING
    5.2.8 EMC
    5.2.9 FAILURE ISOLATION AND RECOVERY
    5.2.10 SAFETY REQUIREMENTS
6 DATASHEET REQUIREMENTS FOR CUBESAT UNITS
  6.1 GENERAL REQUIREMENTS
  6.2 ELECTRICAL POWER SYSTEM UNIT
  6.3 COMMUNICATION UNIT
  6.4 COMMAND AND DATA HANDLING UNIT
  6.5 ATTITUDE DETERMINATION AND CONTROL UNIT
7 DATASHEET REQUIREMENTS FOR CUBESAT PLATFORMS
  7.1 MECHANICAL INTERFACE
  7.2 ELECTRICAL INTERFACE
  7.3 OPERATION-RELATED INFORMATION
  7.4 SAFETY INFORMATION
  7.5 RELIABILITY INFORMATION
  7.6 OTHERS
8 EXTERNAL ELECTRICAL INTERFACE (UMBILICAL)
ANNEX A (INFORMATIVE) TYPICAL DIGITAL DATA COMMUNICATION FOR CUBESATS
  A.1 I2C
  A.2 SPI
  A.3 UART
  A.4 CAN
  A.5 USB
  A.6 SPACEWIRE
  A.7 ETHERNET
  A.8 OTHERS
ANNEX B (INFORMATIVE) PC-104 STYLE EXAMPLE
ANNEX C (INFORMATIVE) BACKPLANE STYLE EXAMPLE
BIBLIOGRAPHY

Introduction

Introduction is written as follows,

This document provides requirements for internal and external (TBD) interface of CubeSat. There is increasing demand of CubeSat development and utilization worldwide. CubeSats are often built with emphasis on low-cost and fast-delivery. The low-cost *can be achieved by extensive use of non-space-qualified commercial-off-the-shelf parts and units. The fast-delivery is, however, often difficult to achieve when the interface of different units, such as printed circuit board (PCB), do not match each other. The incompatibility can cause significant delay in the satellite project, leading to the loss of business opportunity or academic/technology competition.*

There is also increasing trend that a CubeSat platform that contains all the satellite bus functionalities by a single vendor is combined with a mission payload. If there is a common standard on the interface between the CubeSat platform and the mission payload, it will broaden the choice for the those who want to do a space mission but not want to build a satellite to select the platform depending on their needs. The standard will make it easier for CubeSat vendors to enter the market of CubeSat platforms.

This document aims to shorten the time required to design, develop, assemble, integrate and test CubeSat by clarifying the interface from the beginning of the satellite project. The document also aims to promote international trade of CubeSat units/platforms and international collaboration.

Scope

The scope is written as follows,

*This document describes internal and external (TBD) interface of CubeSat. The internal interface includes the interface between components and the interface between a CubeSat platform and a mission payload. The document also describes the items to be included in the datasheet of the CubeSat components and platforms. The interface between CubeSat and its deployer, i.e. POD, is not included in the sc*ope.

Other Contents

Other contents will be distributed at the project website, https://lean-sat.org/, and will be discussed in various occasions.

CONCLUSION

In 2019, a new project to standardize the CubeSat electrical interface started. The project is based on the heritage of the small satellite related standard activities, such as ISO-19683 (testing) and ISO-TS-20991 (requirements). The project aims at registering at new work item at ISO/TC20/SC14 in summer 2021 by summer 2021 and publish the standard by fall 2024.

The project is open to anybody who are involved in CubeSat as developers, vendors, users, and others. It is coordinated through the official website of lean satellite community, https://lean-sat.org/. The lean satellite community evolved through the IAA study group that worked on ISO-19683 and ISO-TS-20991.

The discussion will be done utilizing various international gatherings of the CubeSat community. The International Workshop on Lean Satellite – 2020 is planned to be held in December 2020, although whether it will be done physically or virtually is still under discussion. The project is not simply writing a document. There will be research activities to accelerate the satellite delivery time and promote the satellite mass production. The research outcomes will be shared among the participants. Those who are interested in joining the activity should contact the lead author of this paper.

Acknowledgments

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