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Space Systems Engineering Education by Providing Hands-on Practices Using Pico-Satellite Training Kit

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ABSTRACT

We developed new hands-on type course and tool for space systems engineering. This is one of the courses at Aerospace Engineering, College of Science Technology, Nihon University. The goal of the course is to provide the students with space systems engineering experience by assembly, integration & test (AI & T) of "classroom pico-satellite kit HEPTA-Sat". We report the effects of the course and details of pico-satellite kit HEPTA-Sat in this paper. There are two major contributions. The first is that we provide learning opportunity to students with varied background from departments of art, government officials and general public as student from aerospace engineering. The second is that the course focuses on verification and validation (V&V) through software and hardware AI & T of pico-satellite kit HEPTA-Sat. We analyzed the effects of the course on the students and found out that the course helped them understand space systems engineering in a short amount of time (ex. 1 day to 1 trimester) and very low-cost rather than conventional space engineering educational kit. These have not been realized in any of the previous engineering courses worldwide.

INTRODUCTION

Recently, CubeSat, an ultra-small satellite, has been actively developed in the level of a university laboratory. Although the ultra-small satellite is smaller in scale than a large satellite, it requires capabilities to build the satellite system by integrating various element technologies, such as mechanical engineering, electronic engineering, and communication engineering (structural design, circuit design, software design), and legal procedures including launch and radio waves. The ultra-small satellite is very effective educational materials not only for space development and for learning the system thinking in which various elements are appropriately combined.

In order to aim to systematize those technologies and knowledge, UNISEC (University Space Engineering Consortium) Japan has implemented the efforts into an information exchange presentation, workshop, and lecture series on satellite development; delivery lessons on space technologies in elementary, junior high, and high schools to increase the interest for space fields; exhibitions and lectures via tie-ups with various events; and outreach activities, such as the event for receiving the radio waves from the orbital ultra-small satellite. [1] Furthermore, UNISEC member has implemented educations of practical manufacturing via CanSat and ultra-small satellite both domestic and overseas. [2, 3]

In order to further expand various efforts under these circumstances, UNISEC has implemented construction of networks for developing creative technologists via CanSat and ultra-small satellites, a consigned project with the expense of promotion and adjustment for space utilization by the Ministry of Education, Culture, Sports, Science and Technology. This is implemented in the aim of providing the higher education program of space technologists for undergraduates and graduates via CanSat and ultra-small satellites of several kilograms as educational materials and of constructing the development program for human resources capable of reaching space, in collaboration with member organizations of UNISEC.

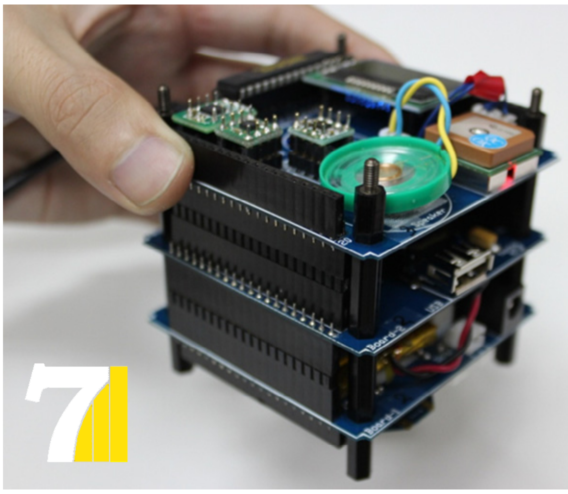

Figure 1: HEPTA-Sat

This educational course and material (hereinafter called "HEPTA-Sat Hands-on Training" and "HEPTA-Sat (Figure 1)") has been developed as part of the above program of construction of networks for developing creative technologists via CanSat and ultra-small satellites of several kilograms for students of elementary school age and older.

HEPTA-Sat is an educational material based on three satellites; SEEDS-1, SEEDS-2 (Figure 2), SPROUT (Figure 2), developed by Nihon University. 4, 5, 6

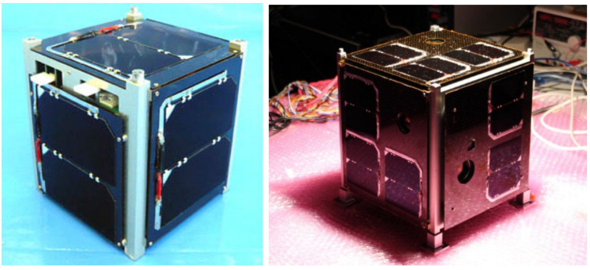

Figure 2: SEEDS-2(2007) and SPROUT(2013)

It is possible to understand the whole satellite system in a short period of time (ex. 1 day to 1 trimester) compared to the existing CanSat and ultra-small satellite project. HEPTA-Sat is designed and developed for a broad range of objectives. Up to the ingenuity of lesson structure, it can be used either in outreach events for general public or college lecture to start CanSat or ultra-small satellite. We have used HEPTA-Sat for educating general public to grab an overall picture of the satellite system through the assembly, integration and test of the satellite component subsystem, as well as using it in lectures at the College of Science and Technology in Nihon University for students trying to build a new system beyond ultra-small satellite, or a hands-on workshop for working people.

This paper is organized as follows. We describe the proposed course and kit overview in Section 2. Section 3 presents the results from the course. We discuss the results in Section 4 and conclude the paper in Section 5.

COURSE OVERVIEW

Training Methodology

In the HEPTA-Sat hands-on training course, Assembly, Integration & Test of satellite system are manually experienced with the HEPTA-Sat. Trainees learns and experiences the concept of satellite systems and functional and physical architecture. An example of the development flow of a satellite is shown in Figure 3.

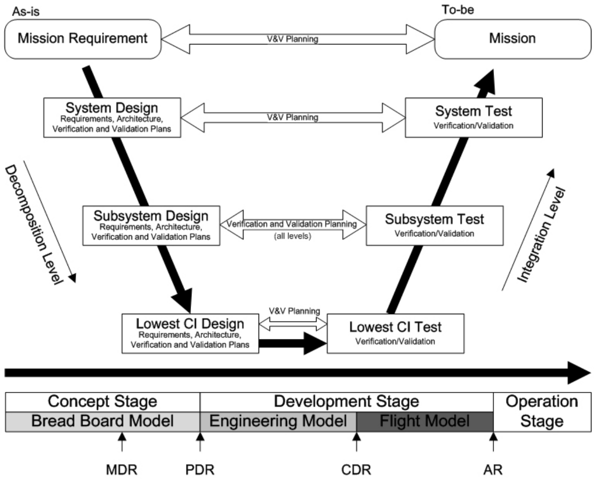

Figure 3: Satellite Development Flow

The left side of the Figure 3 shows the requirement decomposition into the component level, the minimum unit of the satellite system. The workshop derives these functions from the determined mission, clearly specifies the requirement for the subsystem corresponding to that, and instructs how the system, subsystem, and component are selected and designed from the requirement. The trainees will fully understand what should be done in the early phase of system development. (Being too much concerned about fabricating the hardware will neglect this work, which may cause an unnecessary component to be installed or a necessary component to be missing.) Also, roles and behaviors of the satellite system, subsystems, and components are learned via lecture and textbook (Figure 4).

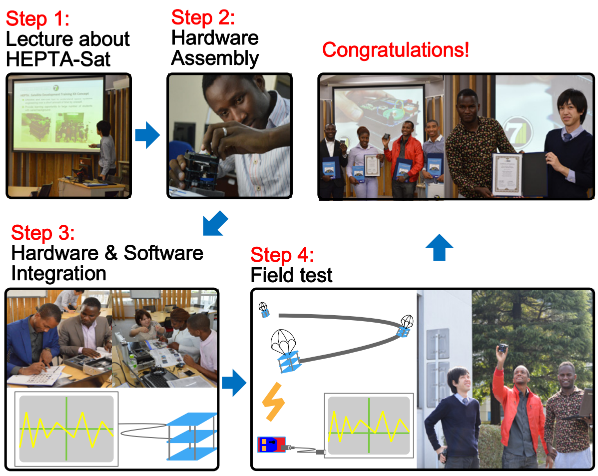

Figure 4: Hands-on Training Course Overview

Their right side of the Figure 3 shows how the component and subsystem are integrated into the system by assembly, integration, and tests. Trainees learn Verification & Validation method by checking that requirements are met at each phase of Assembly, Integration & Test, decomposition, and integration of software and hardware. Questions from trainees are answered by teachers or the teaching assistant. After HEPTA-Sat is finally assembled, individuals and teams devise missions and conduct the field experiments.

Of course, it is possible to arrange for a worktable and solder to make up HEPTA from soldering of components on the board. It is also possible for trainees to design some of the boards by themselves.

Course Schedule

The content and period of the workshop is determined depending on requirements of trainees. Various periods of workshops are available, e.g., one-day or four-day workshops. In our university, the workshop starts by soldering in the class for a term. Depending on the purpose of the workshop, it is possible to delve deeper into it to understand how the component is attained and how the respective parts fulfill the roles, which is an advantage of the HEPTA-Sat workshop. Because various things are considered in selecting components and electronic chips used for each subsystem when actually fabricating the satellite, it might be better to experience HEPTA-Sat at such deeper levels when time permits.

In workshops conducted domestically and internationally, a number of general public and art university students who did not specialize in space engineering attended. The textbook allows beginners (such as junior high and high students) to study the software, hardware, and ultra-small satellites efficiently and systematically on their own. HEPTA-Sat has an advantage in the learning content can be adjusted to variations from only the level of AI & T (Assembly, Integration, and Test) to detailed programming and design and development of electronic board, depending on the purpose and period. Although HEPTA-Sat and the textbook is a kit, it provides the important items to be learned sufficiently because they were created on the basis of our know-how nurtured via actual development, launch, and operation of SEEDS, SEEDS-II, and SPROUT. The trainees can even conduct self-study just by reading the textbook if they have some degree of basic knowledge.

Training Kit

HEPTA-Sat is a 7 x 7 x 7 cm^3 Classroom Pico-satellite educational material (Figure 5). It is a very small ground simulated satellite consisting of six systems: structure, power, command & data handling, communication, ground station, and mission (sensor) in very common with the actual satellite (Figure 6).

Figure 5: HEPTA-Sat Kit

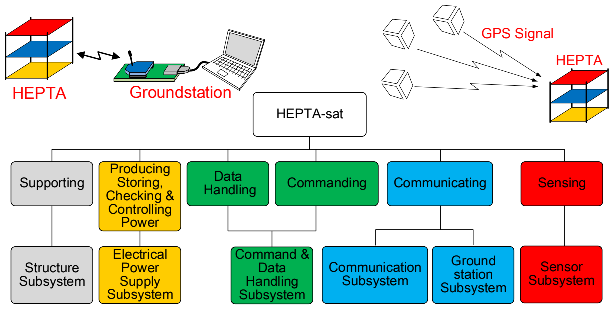

Figure 6: Function and Physical Architecture

HEPTA-Sat functions as the satellite system integrating six functions: support of devices; generation, storage, and control of electric power; data handling; instruction handling; communication; and sensing. Each function consists of six subsystems: Structure, Electrical Power Supply (EPS), Command & Data Handling, Communication (C&DH: transmission and reception, LC and voice interface), Ground Station, and Sensor (angular velocity, acceleration, temperature, camera, GPS). Trainees can learn and experience how to validate the concept, functions, and physical architecture of the satellite system via soldering, assembly, programming of satellite and ground station, and their assembly, integration (including development and implementation of software), and test (field experiment).

The feature of HEPTA-Sat can be described as follows;

- It enabled to understand the component and function of ultra-small satellite including ground station. It can also be used for subsystem and system integration training, such as satellite and ground station software programing, using C++ language and processing language and structure design by CAD.

- HEPTA-Sat can be used either alone or by team. You can learn system engineering through mission planning and making related documents such as mission planning, system specification and project management plan.

- HEPTA-Sat is equipped with sound conversion IC and LED. It can be utilized not only as an educational material for space engineering and satellite development, but also as more general system engineering learning tool.

- Almost all major onboard equipment is removable and can be assembled and integrated repeatedly.

- If designed to satisfy electrical and mechanical interface condition, it is possible to easily add or change the experiment module. Users can design, manufacture and integrate their own circuit board to run an original mission.

HEPTA-Sat consists of three boards. As shown in Figure 7, the top one is the mission system board, the middle one is the C&DH board, the bottom one is the EPS and Communication board. Each board is physically connected via the spacer, and electrically connected via the pin socket. All signals and powers on each board are transmitted and received via the pin socket (Figure 8).

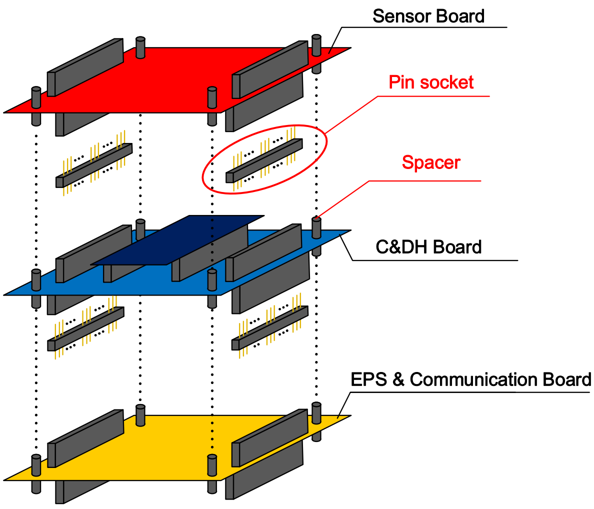

Figure 7: Board Physical Interface

As explained earlier, each board is electrically connected via the pin sockets and physically connected via spacers, in both sides. On the board, No. 1, No. 20, No. 40, and No. 21 are assigned to the upper left pin, lower left pin, upper right pin, and lower right pin, respectively, and the function of each pin is predefined as shown in Figure 8. Pin assignments of all three boards are the same. The user-specific board can be installed as long as the pin assignment is observed. However, it is necessary to confirm that not only physical and electric interface are established, but also conditions of power supply are met.

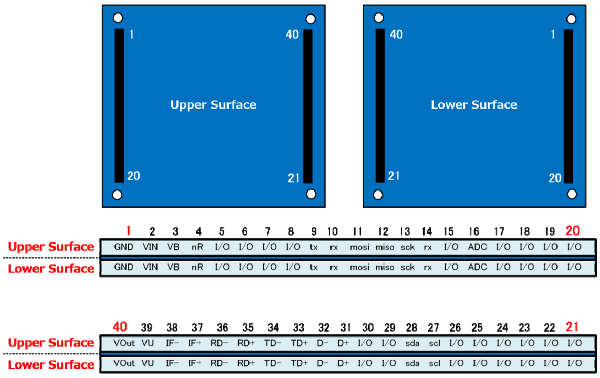

Figure 8: Board Electrical Interface

Course Goal and Target

HEPTA-Sat Training is an education with the aim of experiencing the development process of ultra-small satellites in a short time and acquiring the basic knowledge of space engineering. Although HEPTA-Sat is small and cannot be launched into orbit, it is evidently a satellite in the art, which allows the user to experience various types of problems, such as ones encountered by real satellites. For example, it is important to check in a variety of prior tests that it operates as designed because the real satellite is non-repairable. It is also important to construct the ground station system because the satellite must be remotely operated. HEPTA-Sat allows the users to learn and experience the concept of satellite system, functional and physical architecture, system validation via Assembly, Integration & Test (AI & T) of missions and buses and ground stations that support missions. For example, it is also possible to conduct the training for constructing the ground station system in which the data downlinked from the satellite is visualized so that the ground operator can instantly understand and determine the current status of the satellite.

A number of systems, including large satellites, can be recognized as two functions: partial functions and the overall function that is performed by the aggregate of partial functions. It is true that in the design, development, and operation of actual giant systems, role sharing is performed securely in the situation where multiple departments are in charge of element technologies and another department aggregates them. However, if part and the whole affect each other, human resources are required who are able to address the viewpoints of both part and whole and to work toward overall optimization. Therefore, what is emphasized in the workshop with HEPTA-Sat is to realize the flow and concept of system development, such as learning how to achieve the whole system with some functions when constructing the system to fulfill the functions by studying the concept of satellite systems; functional and physical architecture; system validation via Assembly, Integration & Test; understanding the roles of respective subsystems constituting the whole system, understanding the procedure for integrating those subsystems into the whole system to learn the debugging method, and learning how the whole system and subsystems affect each other.

These learning experiences can create opportunities for in-depth study of the significance, mission plan, specialized theory, design, development, experiment, and later evaluation of satellites. Another feature of HEPTA-Sat is the very low cost for the life cycle. This gives an opportunity for education and consideration of space utilization to many students from universities, higher professional schools, junior high schools, and elementary schools as well as general citizens. The intended users are people who are interested in space engineering. It is hoped that you widely use this material for applications including springboard and learning of ultra-small satellite engineering.

RESULTS OF COURSE

We have conducted workshops. In 2013, one-day workshop was held at the Funabashi campus in College of Science and Technology, Nihon University, consisting of five trainees, one teacher, and two teaching assistants (TA). Participants include a person experienced with CanSat and a beginner who experienced electronic circuits almost for the first time.

The workshop was also held in 2014, at the Funabashi campus in College of Science and Technology, Nihon University, in which students were in charge of trainers. Two students as trainers and one teacher for support served 13 trainees. Participants are undergraduates, graduates, and members of society, and included many students, such as art university students who did not specialize engineering.

The training kit was utilized not only in the above workshops, but also in the overseas training held in the Funabashi campus in College of Science and Technology, Nihon University in 2014, and the four-day workshop for All Nations University College in Ghana in March 2015 (Figure 9).

Figure 9: HEPTA-Sat Workshop in Ghana

Furthermore, we conducted the four-day hands-on workshop for overseas, and the one-year educational project in the Satellite Craft Center performed in College of Science and Technology, Nihon University Department of Aerospace Engineering. In any case, we improved the training-kit by feeding back to it the knowledge obtained during workshop.

We describe here as an example the four-day workshop using HEPTA for five overseas engineers (Figure 10).

Figure 10: Workshop for Overseas Engineers

This workshop was for trainees who tock the basic lecture on space system, and two teachers and three students who were lecturers served five trainees. During a total of short period of four days, we proceeded with the workshop under the plan in which hardware assembly and software development of power supply system, command data handling system, communication system, ground station system, and sensor system were performed while confirming the basic items, such as functions, mechanism, assembly, and total integration, and complying with the Verification Matrix(VM) procedure, and then, in line with those things, integration was performed while confirming the functions as needed. Teachers or students in charge of lecturers answered questions from trainees as needed, and after HEPTA-Sat was assembled, each trainee conceived a mission, created the flow chart, and then made programming. On the final day of the training, test was conducted to check the understanding level. The test included problems on the overall HEPTA-Sat and each subsystem, and problems on conceiving a mission, creating the programming flow chart thereon, and describing it. We used our ingenuity in adding problems that required original thinking to the test. At the same time, a questionnaire on the training was conducted.

From the test result that all five trainees' correct answer rate is 90%, it can be judged that they were able to understand the training content on satellite design. It is also possible for trainees to repeat the assembly, integration, and test again, using HEPTA-Sat and textbook, and to increase their understanding level to close to 100% by self-study. They were able to master the procedure manual and find out new implicit knowledge and formalize improvements of documents by exercising their ingenuity and recording their questions and improvements found in the lecture as needed. The arrangements for prompt reply to questions allowed the implicit knowledge to be found early. The obtained knowledge was fed back to the training kit.

DISCUSSION AND LESSONS LEARNED

In common with workshops conducted in the past, trainees confirmed functions, mechanism, assembly, integration, and each basic item in lectures or documents, and then performed hardware assembly and software development of power supply system, command data handling system, communication system, ground station system, and sensor system while complying with the procedure table. Specifically, trainees learned the design concept of power supply system and communication method of electric signals (serial or parallel communication) for ultra-small satellites, communication method between satellite and ground station, communication protocol, and analog-to-digital conversion via A/D converter, and practiced the development of OBC software with C language and the development of ground station software. Integration was performed while confirming the necessary functions at any time, and mentors answer questions from trainees. When the HEPTA-Sat was finally built up, each trainee or team devised missions, created the flow chart, developed the software, and conducted the field experiment.

After the class conducted by trainees experienced with CanSat project, it was highly evaluated in the questionnaire that overall satellite was able to be handled at the individual level. Although the development of CanSat or ultra-small satellites is a small-scale project, the project is divided into respective tasks, each of which is functioned, which tends to essentially limit the overall knowledge and experiences. Meanwhile, in the cases of CanSat and ultra-small satellites and other cases, it is important to build up individual subsystems while considering the overall system in order to establish the system. It is considered that this training kit work effectively as one for bridging such a gap to handle the overall system in the individual level before starting the actual project. We also received a comment that the basic knowledge should have been prepared. We will improve this point.

In these workshops, we took a style for proceeding with the procedure manual systematically. This is regarded to be an effective way in terms of awakening the interest or capturing the entire picture in satellite. In contrast, for the overseas training, we were able to find the style for learning the satellite system through trainees' own ingenuities and repeated questions in just proceeding with the instruction manual because the training was for trainees who took the basic lecture on space system. To address various levels of hands-on classes, we will consider the mechanism in which presentation of prior learning, problem setting, procedures, and answers are individually adjusted and the learning achievement obtained is visualized to some extent, in order to organize the effective classes.

CONCLUSION AND REMARKS

We started a hands-on course for space systems engineering using ultra-small satellite training kit HEPTA-Sat. The goal of the course is to provide the students with space systems engineering experience by assembly, integration & test (AI & T).

Nowadays, HEPTA-Sat is used as a training kit for a wide range of people, such as being used in a workshop for the public who want to know about satellites and overseas working people who aim to develop satellites. I hope to utilize it as a springboard for the public (children of elementary school age and older) and people in the other fields to learn the space engineering, and as university teaching staff, I am also conducting educational activities for students, in which the practical situation is provided to determine how research activities are joined with society or to create an opportunity to consider it by planning and operating such things with students.

We have decided to continue this course after modifying the contents by reflecting the lessons learned. We will monitor the individual changes of students to develop a more efficient and effective course and prepare a similar course for corporations as future work.

Acknowledgments

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