Development of XML and IP Based Distributed Ground Station System for Pico / Small Satellite

Naoki MIYASHITA and Saburo MATUNAGA
Dept. of Mechanical and Aerospace Engineering, Tokyo Institute of Technology, Japan

Abstract
In this paper we describe proposing and developing of the XML (Extensible Markup Language) and IP (Internet Protocol)-based distributed ground station system for pico-satellites and small satellites. In recent years, universities and space agencies all over the world have been developing small satellites because they are interested in the short-term and low-cost development. We Tokyo Institute of Technology, Laboratory for Space Systems also have been developing small satellite and launched our two satellites which were CUTE-I (CUbical Tokyotech Engineering satellite-1) and Cute-1.7 + APD into orbit actually. In this paper, we proposed the architecture of the XML and IP-based distributed ground station system which consists of multi-functional layers, developed the ground station system, and consulted experiments of CUTE-I and Cute-1.7 operation by using the system actually. Finally, we described the result of the experiments and the conclusion.

1. Background
In this decade a lot of space agencies and universities all over the world have begun to develop small-satellite and pico-satellite enthusiastically and many satellites have already been launched into orbit and operated actually. We Tokyo Institute of Technology Laboratory for Space Systems (LSS) also developed two pico-satellites which were CUTE-I (CUbical Tokyotech Engineering satellite-1) and Cute-1.7 + APD and launched them into their orbits as the piggyback satellite. We have already been operating CUTE-I for over 3-years without remarkable troubles since the launch. These facts shows the potentials of pico-satellite regarding the lower developing and launching cost, the short-term of the development, and abundant launching opportunities by piggy-back launch.

The latest technologies on semi-conductor, which realize small package, low power consumption, and low price in spite of the high performance, also contribute to developing pico-satellites greatly. On the other way, the limitation of electrical power from the solar cell for the reason of the small area of solar cell leads to restrict the electrical transmitting power of communication subsystem, thus most of pico-satellite can’t have enough high speed communications inevitably. For this low-speed problem, two approaches are proposed. First is to configure the constellation system by multi satellites in order to increase the total data of transmitting from low-speed small satellites. The other is to configure the wide-area distributed ground station systems which are located in wide area in the world in order to increase the visible operation duration between the low-speed satellite and ground station. Therefore, we need the wide-area distributed ground station system which can operate multi series satellites.

Moreover we adopted amateur radio band as the communication band because of the easy acquisition of transmitting frequency which is arranged and assigned internationally and easy development by using COTS (Commercial Of The Shelf) amateur
transceiver. The communication by using amateur band has often jammed by other illegal amateur’s use and we have experienced that the telemetry data from amateur satellites were lost many times for this 3-years operation by jammed radio. For this jamming problem, we need the narrow-area distributed ground station system in order to complement jammed data each other among some ground stations which is located in narrow area enough to get telemetry from the amateur satellite simultaneously.

Furthermore the human fatigue for ground operation of everyday is not-ignored problem from the over 3 years’ student-based operation, therefore the autonomous ground operation has been needed.

2. Objectives

Objectives of this paper is to propose the architecture of ground station system which has the following features or functions, to develop the framework software system based on the proposed architecture, consult the ground operation with the developed system by using our satellite CUTE-I and Cute-1.7 + APD.

- Extensibility for multi-series satellite system; future ground station will be required that one ground station system which belongs the distributed ground station system can operate many types of satellite.
- Wide and narrow area distributed system; not only to increase visible operation duration but also complement jammed telemetry data each other.
- Autonomous function in order to decrease the fatigue of ground operator.
- Low-cost and short-term developable system

3. Existing Satellite System

3.1 CUTE-I

CUTE-I is our first handmade pico-satellite by student. CUTE-I is based on Cubesat Design Specifications defined by Cal Poly and Stanford Space Systems Development Lab. (SSDL), 10cm-cubed shape, and 1kg weight pico-satellite. CUTE-I was launched from Russian rocket ROCKOT on 30th June 2003. Figure 1 shows CUTE-I flight model.

3.2 CUTE-I Communication Subsystem

CUTE-I always transmits CW (Continuous Wave) beacon including Morse code by using 430MHz amateur band with interval among frames in order to reduce the power consumption. CW beacon include the house keeping data, e.g., satellite bus voltages, temperatures, satellite status. Figure 2 shows normal CW beacon frames. The other hands, CUTE-I adopts amateur radio band; therefore CW telemetry is often jammed by other illegal radio as shown Figure 3.

CUTE-I also has FM packet downlinking communication which is faster baud rate (~1200bps) than CW beacon, requires much power consumption of transmitting, and includes of all CUTE-I data, for example, gyroscope data, accelerometer data, sensor data, and so on. FM packet is also jammed by other illegal radio.

3.2 Cute-1.7 + APD

“Cute-1.7 + APD” is our second developing satellite which is 10cm x 10cm x 20cm as shape and 2kg as weight. We launched Cute-1.7 + APD on 22nd Feb 2006 by JAXA (ISAS) M-V rocket 8 from Uchinoura Space Canter in Kagoshima Japan.

4 Ground Station System Architecture and Framework Software

We proposed an architecture for extensible and distributed ground station system for small satellite. The concept of the architecture is superior to system...
extensibility, data reusability, and low-cost by using the latest Internet technologies and XML (Extensible Markup Language) document technologies. Functions of general ground station system not to be related to the scale of the system can be classified into five primitive functions.

- Controlling ground station equipments
- Storing and managing the data of ground station
- Analyzing, calculating, and handling data.
- Administrating and utilizing ground station.
- Publishing and presenting several data of satellite telemetry and ground station system.

Proposed architecture of ground station system is multi-layered distributed system which consists of the following abstract five layers which are in charge of these primitive five functions as shown in figure 5. The five layers are connected each other via IP (Internet Protocol) network and XML data format.

- Equipments Control Layer: Controlling ground station equipments, e.g., antenna direction, radio frequency.
- Data Store Layer: Storing and management all data of ground station.
- Business Logic Layer: Analyzing and calculating data regarding ground station and satellite and storing data into data store layer
- User Layer: Administrating ground station and checking and using ground station data.
- Presentation Layer: Publishing satellite telemetry or ground station data into Internet for worldwide researcher and general people.

We developed the ground station framework software based on the proposed architecture with Open Source System (OOS) in order to reduce the development cost. The Operating System (OS) consists of Linux, the framework software consists of C++, Java (J2EE), C#, and the servers consist of Open Source Servers which are MySQL, JBoss Application Server, Apache web server. The functions of each layers have common function to all ground station system, e.g., orbital calculation function and orbital estimation on business logic and antenna direction control on equipment control layer. The framework software provides basic structure of five layers which can access each other via XML data (GSML) on IP network. The framework consists of function modules by Object Oriented Programming, therefore we can implement additional function module into the framework easily. The framework has already had several common functions for all ground station system as function module. Thus, when we extend this ground station system for future satellites, we develop only function modules for the specific satellite. This function module system contributes to short-term and easy development. Figure 6 shows developed ground station framework software.

This framework manages all ground station data as XML data because XML can supply accurate data handling, easy reformatting, easy parsing with many existing XML parser, and i18n (Internationalization). This framework software uses some kinds of XML schemas and languages. GSML (Ground Station Markup Language) which is original XML-based language for this framework and manages all status of ground station equipments, antenna direction, radio frequency, received telemetry data, and sending command data as XML data. GSML is handled between business logic layer and equipment layer via TCP/IP socket communication and stored into datastore layer. Figure 7 shows a sample of GSML.
5. Development of Additional Function Modules

5.1 Remote-Controllable Module

The most serious cause for operator’s fatigue is to go to the ground station system on such early time. This ground station framework is based on IP network on the communication between layers; therefore operator can control and administrate ground station system from all over the world. In this time we developed 1) remote AC(Alternating Current) controller via IP network in order to reduce power consumption of ground station system, 2) remote camera system in order to check the situation from remote site, and 3) remote audio transfer system via VoIP (Voice over IP). By using these additional remote-controlling systems we can operate satellites from our home via broadband Internet. With regarding to the communication delay issue between home and ground station this framework can solve it by local feedback for high-speed control frequency such as controlling radio frequency with Doppler shifting. Because the user layer host is located in the ground station LAN (Local Area Network) via VPN (Virtual Private Network), the remote-control access is secured.

5.2 Satellite Contents Provider (SCP) Module

SCP module is responsible to analyse telemetry data, reformat from raw data to several suitable format for user, generate operation result automatically, and publish the publishable telemetry data in real-time. By using SCP, troublesome operations of the ground operator can be reduced. SCP has the connector module interface which can have many kinds of connector modules. Connector module is a module program which consists of analyzing part, reformating part, and publishing part for the specific satellite telemetry format. Therefore, when the future satellite will be developed, we develop only this SCP connector module for the satellite and implement it into the SCP interface. We developed fundamental connector modules as the follows.

- RSS (Rich Site Summary) broadcasting connector is to broadcast the satellite telemetry as RSS (Ver.1.0, Ver.2.0, and ATOM) format in real-time. RSS is very remarkable data format and data distribution system in recent years.
- XML + XSL connector is to broadcast satellite telemetry is to broadcast the satellite telemetry with proper XML format for the user by XSL (T) engine in real-time.
- WEB connector is to publish the satellite telemetry with XHTML web language in real time. By this connector, not only researcher but also general people can access precious satellite data, e.g. space images on the orbit, by general web browser.
- Real-time GIS (Geographic Information System) connector is to connect external GIS systems, e.g. Google Maps, and so on, and send the telemetry data with GIS format in real-time. This connector can connect Google Maps, Google Earth (KML), and Microsoft Virtual Earth.
- SOAP / XML-RPC connector (Web service connector) is to connect external web service server by XML-RPC or SOAP protocol, and push the telemetry data in real-time.
- SMTP connector is to send E-Mail which includes the telemetry data in real-time.
- RDBMS (Relational Database Management System) connector is to publish SQL queries to major RDBMSS and to store the telemetry data.
- Dashboard connector for Mac OS X is to broadcast the telemetry data into Mac OS X Dashboard interface in real-time.

By using these fundamental connectors, our ground station system can analyze, reformat, publish, and broadcast the telemetry data in the proper format in real-time. SCP is also contributed to reducing the
fatigue of ground operator. We are going to show the application examples of the SCP as follows.

- **CUTE-I Blog System (XML-RPC Connector)**

  CUTE-I Blog system is shown in Figure 9. CUTE-I Blog system is CUTE-I’s automatic weblog system by using XML-RPC connector. One entry log includes telemetry data, data timestamp, and location data. Thanks to popular weblog style, general people can access easily and mash up the telemetry data into other data on the WEB2.0. Moreover CUTE-I blog system also publish RSS feed by using the RSS broadcast connector, therefore general user and search robot can access the telemetry data by RSS reader. This blog system can be contributed to the advanced use of the satellite telemetry.

- **Realtime GIS System (Realtime GIS Connector)**

  Many kinds of GIS, e.g., Google Maps, Google Earth, Microsoft Virtual Earth, have been opened in recent years. Those GIS systems have many types of data which include geometric and location information. SCP can provide satellite telemetry data into those GIS systems by SCP GIS connector in real-time. Figure 10 shows CUTE-I telemetry data on Google Maps.

5.3 **Autonomous Operation Module**

We developed autonomous operation function module by using remote-controllable module and SCP module.

5.3.1 **Ground Station Operation Scheduler and Sequencer**

For autonomous operation we developed ground operation scheduler. Operator can access this system by web browser, cellular phone, and PDA (Personal Digital Assistance) from anywhere and can schedule automatic operation. This scheduler generates the list of visible pass of any satellite and operator can select the target pass to operate.

The followings show the procedure of operation by this autonomous ground station system.

1. Operator selects visible pass from the list generated by ground station operation scheduler via web browser.

2. Ground station scheduler generates all tasks to do satellite operation and store the tasks ground station task database.

3. Ground station sequencer always checks the ground station task database every minute and carry out the tasks in accurate time. For example, 1) Turning on ground station system before operation time via remote controllable module, 2) Tracking satellite with Doppler shift, 3) analyzing, calculation, reformatting, and publishing by SCP module, and 4) turning off ground station system after the operation.

5.4 **Distributed Ground Station System Module**

We developed distributed ground station system module. To Connect and configure distributed ground station each other, this module implements SOAP-based distributed connection protocol. The protocol is configured three layers which are
infrastructure, data transfer, data format layer as shown figure 11. We adopted SOAP protocol and Internet infrastructure as the low 2 level layers because all ground station system can participate in this ground station distributed network easily. Needless to say, SOAP and Internet is very popular all over the world in recent years.

![Figure 11 Protocol Model](image)

**Data Format Layer: Ground Station Control Protocol (GSCP)**

Ground Station Control Protocol (GSCP) defines services’ format of controlling distributed ground station system remotely. Table 1 shows GSCP services. By adopting GSCP on SOAP protocol, distributed ground station system can access and control each other via Internet.

![Table 1 GSCP Services](image)

<table>
<thead>
<tr>
<th>Method</th>
<th>Param1(type)</th>
<th>Param2(type)</th>
<th>Param3(type)</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>GetAzimuth</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Azimuth(double)</td>
<td></td>
</tr>
<tr>
<td>GetElevation</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Elevation(double)</td>
<td></td>
</tr>
<tr>
<td>GetFrequency</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Frequency(int)</td>
<td></td>
</tr>
<tr>
<td>SetAzimuth</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Azimuth(double)</td>
<td>Status(string)</td>
</tr>
<tr>
<td>SetElevation</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Elevation(double)</td>
<td>Status(string)</td>
</tr>
<tr>
<td>SetFrequency</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Frequency(int)</td>
<td>Status(string)</td>
</tr>
<tr>
<td>GetGSStatus</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>GS Status(string)</td>
<td></td>
</tr>
<tr>
<td>GetModulation</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Modulation(int)</td>
<td>Status(string)</td>
</tr>
<tr>
<td>SetModulation</td>
<td>ID(string)</td>
<td>Pass(string)</td>
<td>Modulation(int)</td>
<td>Status(string)</td>
</tr>
</tbody>
</table>

6. Ground Operation Experiment of CUTE-I

We have been doing ground operation of CUTE-I with developed ground station system for more over 3 years. In this long use we didn’t have remarkable troubles, therefore this architecture and framework software is reliable system. Moreover when Cute-1.7 + APD was launched, we could develop only SCP connector module for specified Cute-1.7 + APD telemetry format and implement it easily, therefore, this system has extensibility for multi satellite operation.

6.1 narrow-area distributed ground station operation experiment.

We consult narrow-area distributed ground operation experiment. Four distributed ground stations in Japan did ground operation for CUTE-I simultaneously and complement the telemetry each other. Although the each telemetry was sometimes jammed by illegal radio, the complemented telemetry from four ground stations included all transmitted telemetry as shown figure 10.

![Figure 12 Narrow Area Distributed Experiment](image)

7. Conclusion

we proposed the ground station architecture which consists of multi-layers, developed the ground station framework software based on the architecture which can provides primitive ground station function and implement specific functions as function module easily. By using the function module interface, we developed remote-controllable module, Satellite Contents Provider (SCP) module, autonomous operation module, and distributed ground station module. We consult long-term CUTE-I operation with the developed ground station system and narrow-area distributed ground operation in order to complement jammed telemetry each other.

REFERENCES