CITIZEN EXPLORER – A LOW-COST, DISTRIBUTED AND INCREMENTALLY AUTOMATED MISSION OPERATIONS SYSTEM

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ABSTRACT

The Colorado Space Grant Consortium (CSGC) has developed a low-cost, distributed and incrementally automated mission operations system. Automation technologies are being applied to support mission operations flexibility, user interaction, beacon assessment, autonomy migration, failure mode and effects analysis, and the use of integrated planning and scheduling capabilities. The application of such technologies becomes critical for low-budget spacecraft missions. Our goal is to implement a system that is not cumbersome, that can be learned quickly, that can automatically monitor the health and status of the spacecraft and respond to any anomalies. Automating components of the operations system will result in more cost-effective operations due to a significant reduction in operations staffing. In addition, automation allows us to focus on complex fault handling, opportunity management and the demonstration of new technologies.

The forum we will use to demonstrate our mission operations system is the Citizen Explorer-I (CX-I) spacecraft currently being designed and built by a team of undergraduate and graduate students at the University of Colorado, Boulder. CX-I is designed for a sun-synchronous circular orbit with a 10:15AM/10:15PM equator crossing and an altitude of approximately 700 kilometers. This orbit will provide limited access time with our ground stations in Boulder, Colorado and Fairbanks, Alaska. Due to the limited access time, it is imperative that we implement a robust planning and scheduling scheme. To meet this need, CSGC has developed the Citizen Explorer Design and Operations Planning System (CXDOPS). CXDOPS (Figure 1) was designed to support mission design, systems modeling and mission operations. Several components make up this system. The first is a Commercial Off-The-Shelf (COTS) tool called the Satellite Tool Kit (STK). STK was developed and donated to CSGC by analytical Graphics Incorporated (AGI). STK is a satellite system modeling, analysis and visualization tool. STK is used to generate reports to be used by CXDOPS. These reports include ground track information, ground station access times, terminator crossing times and other data relevant to the spacecraft model.

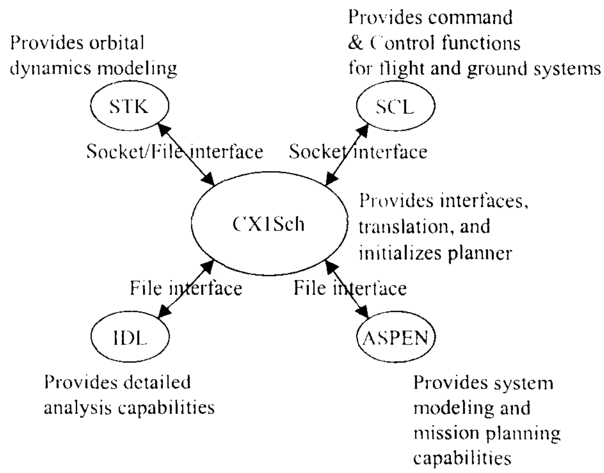

Figure 1: Citizen Explorer Design and Operations Planning System

The next component is another Off-The-Shelf (OTS) tool called ASPEN (Automated Scheduling and Planning Environment). ASPEN is a suite of planning and scheduling software developed by and provided to CSGC by the Jet Propulsion Laboratory (JPL) for use with spacecraft missions. This software generates sequences of low-level spacecraft commands from a specified set of high level science

Proc. Fifth International Symposium on Artificial Intelligence, Robotics and Automation in Space, 1-3 June 1999 (ESA SP-440)

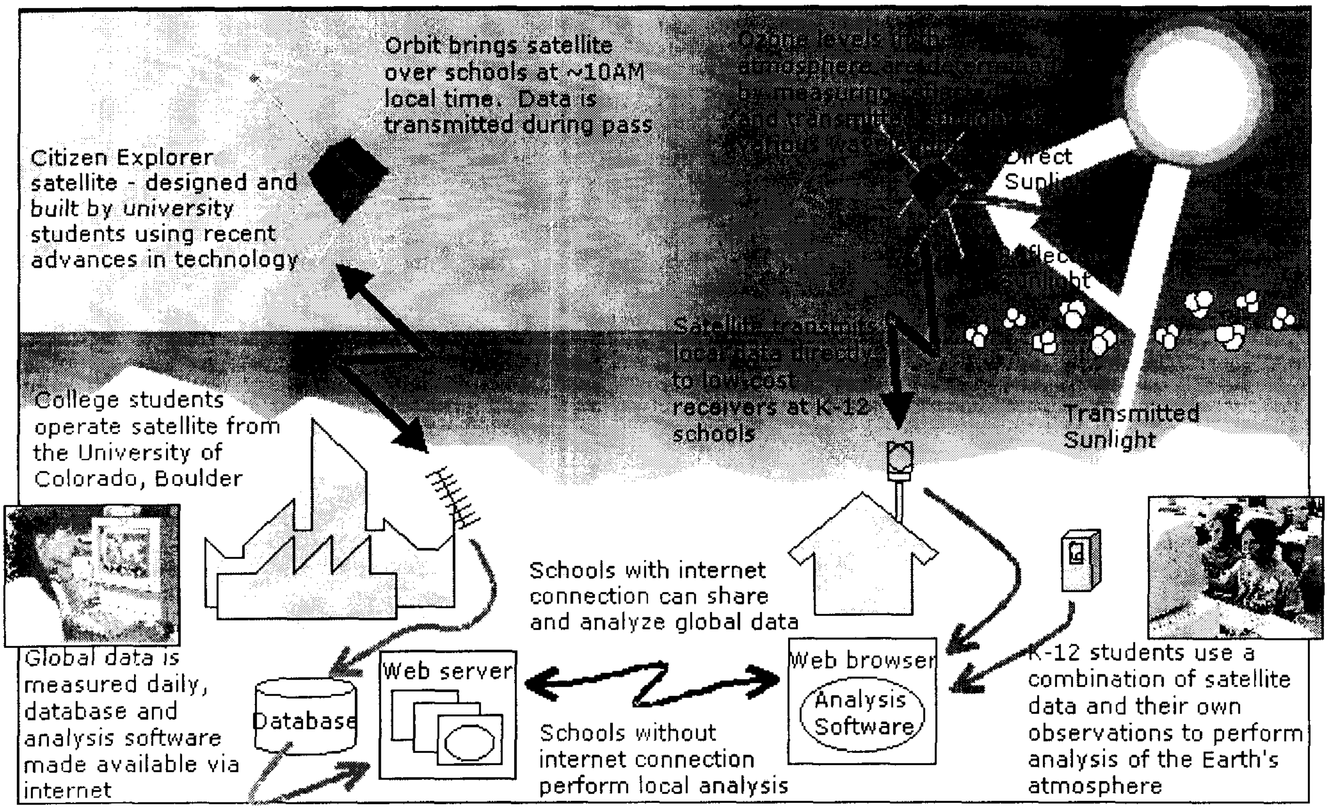

Figure 2: CX Concept Architecture

and engineering goals. ASPEN encodes complex spacecraft operability constraints, flight rules, spacecraft hardware models, science experiment goals and operations procedures. From these inputs, ASPEN automatically generates low-level spacecraft sequences. ASPEN is used in CXDOPS for system design visualization and mission planning.

The heart of CXDOPS is CX1Sch (Citizen Explorer – I Scheduler). CX1Sch is a Java program developed at CSGC, which provides transparent communication interfaces between each component of CXDOPS. CX1Sch also provides the Graphical User Interface (GUI) to CXDOPS. The GUI allows the operator to adjust various parameters, which enables them to perform several tasks using the CXDOPS system, including running various simulations which assist in the design process and system modeling. Planning and scheduling scenarios can be run for various portions of the mission. During the mission, CXDOPS will be used to perform orbit prediction and analysis, determine access times, perform spacecraft analysis, create goals and activities for the planning system and optimize schedules.

Failure Mode and Effects Analysis (FMEA) is being used to make decisions prior to launch that are reflected in flight and ground software in the form of scripts, rules and constraints implemented in Spacecraft Command Language (SCL). SCL, a product of Interface and Control Systems, Inc., is a portable, distributed, intelligent command and control system. Decisions are based on the results of the FMEA process where first, the subsystem teams identify potential failures. Those who designed the system and are familiar with it most easily predict failures at this level. The criticality of these failures is preliminarily ranked by the subsystems. The main measures that are taken into account are impact of occurrence (what effect this failure would have on the mission if it were to occur), probability of failure (the likelihood of this failure occurring) and detection (the ease and promptness of detection). A secondary measure is also used to determine the chance of controlled recovery. This information is used both within the subsystem and at an overall systems level to prioritize and concentrate mitigation efforts. In addition to analyzing the criticality of each failure, the cause of failure and symptoms are documented. From this point both mitigation and contingency plans are formulated and the flight software is updated to reflect these plans. Using SCL, we will migrate knowledge gained to the flight system both during system integration and throughout the mission. SCL will be interfaced to the CXDOPS system, specifically, the low-level spacecraft sequences generated by ASPEN will be mapped to sequences in SCL. Sequences generated through CXDOPS can then be uplinked and executed on the spacecraft.

Another OTS tool we will be using for the CX-I mission is SELMON (Selective Monitoring). SELMON was also developed and provided by JPL. SELMON and SCL together perform realtime monitoring and evaluation of engineering health and status data. Using SCL and SELMON data, beacon summaries of overall system performance are produced. These beacon summaries will be sent as spacecraft telemetry, which will be received by mission operators at the beginning of each pass, allowing the operators the maximum amount of time to react to any changes in system performance. To further enhance the usefulness of the beacon assessment technology, we will downlink the beacon summaries to K-12 schools participating the CX-I program. Schools across the state of Colorado, the United states, and eventually throughout the world will be equipped with an EduStation (Educational Ground Station) which consists of a receiver and a personal computer running a variety of applications software. The EduStation will enable K-12 students to monitor the spacecraft as it passes overhead. In the event that a school detects a change in the spacecraft performance, they can alert the CX-I mission operations team, giving them time to prepare the necessary plan of action for the next Boulder or Fairbanks pass.

The high level information displayed to students using the EduStation is the end product of the entire EEMOS (End-to-End Mission Operations System) software system. EEMOS consists of embedded flight software running aboard the spacecraft as well as a wide array of proprietary and COTS applications running on the ground, which produce downlink, parse, process and store CX-I data. These applications will produce secondary data products that will be sent to and displayed at the EduStation while all of the underlying distributed software will remain transparent at the EduStation level.

The front-end software (GUIs) for the mission operations system provides users with a high level interface to a complex and distributed software system by making extensive use of Web applications written using a COTS software package called Sammi (Kinesix Corporation), as well as HTML, Java and CGI. This approach enables a powerful, distributed, cross-platform, easy-to-use interface for all users by making extensive use of the well established web based protocols and software. The EduStation interface running at participating K-12 schools will present informative displays that clearly represent both engineering and science data. Software applications written in Java will enable K-12 students to view 2D graphical displays that reflect the current health and status of the satellite. Schools will receive broadcast packets during a satellite pass that will contain valuable science and engineering data. Java applications will parse the raw data that is received and create a series a images that will include thermometers and power gauges representing current voltages and temperatures of the satellite's subsystems. Beacon summaries that are included in the downlink will also be graphically displayed. Science data taken from the satellite and K-12 handheld devices will be calibrated to determine more accurate UV and ozone data values. Science data will be represented by a series of Java applets and IDL images that will include line, bar and contour graphs. Both science and engineering data will be displayed through informative and interactive graphical user interfaces at participating K-12 schools that will help the CX-I operations team monitor the spacecraft.

The object-oriented design methods used to implement the Java applications and applets will encourage reuse and maintainability. Software applications are being designed with abstract interfaces and minimal dependencies between classes. This object-oriented implementation will reduce future costs that are required to reuse and maintain the software applications. The CX-I mission and future missions will benefit from Java's cross-platform capabilities, minimizing the need to port to different platforms used by the K-12 schools. Java distributed nature also encourages high-level support for networking. Java applets will be used to frequently download and display historical science data across the Internet. The Graphical User Interfaces running on the schools' Web browsers will benefit from Java's built-in multithreaded environment by improving the interactive performance. Java's object-oriented, interpreted, distributed, and robust characteristics make it an ideal choice for the CX-I ground-level software development.

The mission operations interface, also sitting atop the aforementioned distributed EEMOS system framework, will provide both scientists and engineers with powerful command and monitoring abilities. Scientists will have access to both the ground and flight science data archives as well as realtime control of the science instrument aboard the spacecraft. Operators will have the ability to issue commands, monitor sensors, run diagnostics, access both ground and flight databases, update the SCL project and database and perform code updates. Performing such updates allows for a high level of flexibility in the mission operations system. CSGC heritage has proven this flexibility is vital for a robust and optimized system as it allows the mission operations team to tailor the system to best meet the needs of the spacecraft. At the start of the mission, before spacecraft flight behavior is well characterized, operations personnel monitor the system very closely. This requires a larger operations team to handle any anomalies that might occur or to make changes to the flight and/or ground system. As the mission progresses and spacecraft performance is characterized, operators introduce increased autonomy via additions and updates to existing scripts, rules, constraints, sequences, and operational procedures. This capability enables the system to be incrementally upgraded based on the needs of the spacecraft. Once these updates have been performed and the system has been sufficiently tested with the new updates, the cost of operations is decreased by allowing a significant reduction in operations staffing.

The demonstration of the CX-I EEMOS will result in a mission operations system that can be applied to a variety of spacecraft missions. EEMOS demonstrates that robust, automated operations systems can indeed be developed for missions with a modest budget.

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