RECONSO: Low Earth Orbit Object-Detecting Nanosatellite

ECE4012 Senior Design Project

Team Toybox
Project Advisor, Dr. Whit Smith

Montana Bowman
Brennen Bukovics
Luis Fernando Lopes
Keary Mobley
Changjun Ahn
Michael Reymond

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Executive Summary

Low Earth Orbit (LEO) is becoming an increasingly dangerous place for spacecraft as a result of orbital debris. This debris increases over time, making it increasingly more dangerous. Efforts have been made to track and characterize large space debris in order to minimize the threat to new and current spacecraft, but most of these efforts do not adequately track smaller objects under 10 cm in diameter. This type of debris, though small, can still cause considerable damage. RECONSO seeks to mitigate this problem.

RECONSO is a CubeSat nanosatellite project sponsored by the Air Force Office of Scientific Research that seeks to use commercially available imagers to track and characterize orbital space debris in the 1 - 10 cm range. The solution exists as a 6U CubeSat set to monitor debris while in a circular polar orbit. When tracking debris, information will be transmitted to ground stations where it can be processed and used to avoid debris in the future.

The satellite will have all subsystems necessary of a typical satellite including, but not limited to Attitude Determination and Control Systems, Command and Data Handling, Communications, Electrical Power Systems, Flight Software, and the Payload.

If all goes well, the completed satellite will be launched in 2018 and will track objects for a period of 6 months before deorbiting naturally. The project is financed by the Air Force Office of Scientific Research and so all cost will be assumed by them

RECONSO: Low Earth Orbit Object-Detecting Nanosatellite

1. Introduction

RECONSO is a Cubesat project aimed at detecting and tracking objects in Low Earth Orbit. Team Toybox will support the RECONSO team in ECE related tasks in order to meet the RECONSO goal of launching into space in early 2017.

1.1 Objective

The team will design and prototype parts of the satellite that will detect and track orbital debris between 1 to 10 cm in Low Earth Orbit. Orbital debris will be observed with a visible light lens and a CMOS imager, and data will be sent to the ground station via Globalstar, a low Earth orbit satellite constellation for low-speed data communications. The satellite will receive power through solar panels while the sun is not shadowed by the Earth. Once the data is received by the ground station, frames that are taken by the satellites will be processed.

Team Toybox will be split into four teams that will each work with different subsystems: Command and Data Handling (CDH), Electrical Ground Support Equipment (EGSE), Communications (COMMS), and Flight Software (FSW). CDH is in charge of communications of different subsystems within the satellite, EGSE is in charge of making test equipment for the satellite, COMMS is in charge of communication between the satellite and the ground station, and FSW is in charge of system health operations and all other software to support satellite operation.

1.2 Motivation

There are more than 21,000 orbital debris larger than 10 cm and estimated over 500,000 particles between 1 to 10 cm [1]. Large pieces of debris (> 10 cm) can be tracked easily by ground station, but smaller pieces can not be easily tracked. In low Earth orbit, these pieces will be travelling at the speed of 6 to 8 km/s, and collisions, even if the pieces involved are small, will cause considerable damage [1]. This is the first CubeSat project whose primary function is detecting and tracking small space debris. The primary customer will be the US Air Force, who is sponsoring this project.

1.3 Background

1.3.1 CubeSat Program

CubeSats are nanosatellites meant for scientific research [2]. They are built with standard dimensions and weights, and are deployed as secondary payloads on a launch vehicle [2]. CubeSats must follow strict guidelines and specifications on the making of the satellite. One such guideline is the material of the satellite, as outgassing must be limited. Another is protocols during and right after being deployed, as the satellite must be powered down during the launch and 45 minutes after being deployed.

1.3.2 Object-Tracking Algorithm

The algorithm for object detection and tracking already exists. It involves three things: centroid identification, track identification, and subtracting known starfield [3]. Centroid identification processes each image to find objects in view: stars in the background and orbital debris that are visible. With objects located, it will run iterative closest point algorithm to find the same objects between each frame and track every object in view. Finally, objects with similar movement patterns are subtracted, as they are assumed to be stars in the background thus only objects in view that are left are orbital debris.

2. Project Description and Goals

Members of the Team Toybox will work with different subsystems of RECONSO. On top of everything that will be done in each subsystems, everything must be documented extensively so that the group that will be working on it after Team Toybox leaves can continue on where it will be left off.

2.1 CDH

- Make a functional breakout board for ADCS board for a microcontroller in charge of sun sensor and magnetorquers
- Make a functional breakout board for EPS board to send power to CDH board and thermal board for dissipating heat
- Have cables securely harnessed between different microcontrollers
- Install and properly configure the Buildroot cross compilation tool
- Implement the method for patching satellite software once in flight
- Configure the SPI connections with the Tyvak Intrepid flight computer
- Install and connect the external port to interface with the satellite for ground testing

2.1 EGSE

- Make a test equipment for the battery of the satellite
- Make a packaged satellite connector

- Integrate with Tyvak and CFE
- Finish implement before PIR

2.2 COMMS

- Establish UHF uplink/downlink to the satellite
- Establish Globalstar uplink/downlink to the satellite
- Transmit and execute satellite commands over RF
- Perform data error checking and handling
- Download telemetry and images from the satellite

2.3 FSW

ADCS Service:

- Must run on a BeagleBone Black (current ADCS computer)
- Transmit health data to the main Tyvak flight computer
- Must receive sensor data from the Tyvak
- Integrate successfully with the rest of the ADCS systems

CFE (Core Flight Executive) App:

- Must run on the Tyvak Intrepid flight computer
- Receive raw sensor data from the Tyvak sensors(magnetometer, gyroscope, etc)
- Transmit requested sensor data to the ADCS subsystem

- Receive health data from the ADCS subsystem and share it with other CFE apps through pipes
- Integrate seamlessly with the CFE messaging service

3. Technical Specifications

3.1 CDH

Table 1. CDH Team Requirements

Item	Specification
BeagleBone breakout board	Y/N
Cable harnessing	Y/N
Buildroot functional	Y/N
Satellite software deployment	Y/N
SPI connections with Tyvak	Y/N
Satellite EGSE connection	Y/N

3.2 EGSE

Table 2. EGSE Team Requirements

Item	Specification
Power charging equipment	Y/N
Packaged satellite connector	Y/N
Goldboard implementation	Y/N
Integration with satellite	Y/N

3.3 COMMS

Table 3. COMMS Team Requirements

Item	Specification
UHF uplink/downlink	>3dB link margin
Globalstar uplink/downlink	Y/N
RF command transmission and execution	Y/N
Data error handling and checking	Y/N
Image and telemetry download	>9600bits/s

3.4 FSW:

Table 4. FSW Requirements for the ADCS Script

Item	Specification
Language	Python
Environment	Debian Linux
Script starts automatically	Y/N
Script is fault tolerant	Y/N
Defines message objects	Y/N
Message serialization	Y/N
Documentation - how to use the script	Y/N

Table 5. FSW Requirements for the cFE App

Item	Specification
Language	C
Environment	Embedded Linux w/ cFE
App registration	Y/N
App makefile	Y/N
Message structs	Y/N
Correctly listens to pipes	Y/N
Writes to pipes	Y/N
Unit test coverage for app	>80%
Documentation - using the app	Y/N

4. Design Approach and Details

4.1 Design Approach

Since Team Toybox is joining an already established project group, many of the major design decisions of the project have already been decided by leading members of RECONSO.

4.1.1 CDH

Within the CDH subsystem, design will be focused on the PCB and working with FSW subsystem. For PCB, there needs to be a cape for ADCS, EPS, thermal subsystem, and GlobalStar's board. For ADCS, the interface board will connect various sensors and actuators that the satellite will use for data collection and to maintain proper orientation to the ADCS microcontroller. For EPS, the power will be sent to CDH board, which will distribute power to other subsystems as needed. Work needs to be done to ensure that Tyvak can communicate with boards of various subsystems. The data output of IMU from Tyvak must be relayed to ADCS board so that the satellite's orientation can be changed as needed. Communication from ground station to satellite is done through GlobalStar board, so it must be able to communicate with Tyvak in order to ensure proper operation.

4.1.2 EGSE

!! and Electrical Ground Support Equipment (EGSE). An EGSE is what allows for the validation and integration of electrical equipment on a spacecraft [4]. This element is essential for a satellite in orbit as it allows for automated health checks to be run, ensuring a problem free orbit.

4.1.3 COMMS

The Design approach of the COMMS subsystem is well described in the Telecom Interface Control Document written by the COMMS team lead. The following quoted portions outline the design approach.

> Mechanical Interfaces
>
> Both communications modules (the NSL Eyestar module and the Tyvak UHF Radio Flight Unit) will be mounted with flat head and socket cap screws to the internal structure of the satellite towards the –X face for proximity to power systems and to reduce signal loss through cabling. The internal mounting scheme of the Eyestar allows for a 30.48 cm length of SMA coaxial cable to the patch antenna mount, which is the maximum specified in the Eyestar Duplex ICD….
>
> The NSL Patch Antenna will be located on the negative X (−X) face of the spacecraft, which is located opposite of the camera. This is to accommodate the

requirement of the camera to face away from the sun and to allow for optimal solar panel placement. To minimize line losses between the duplex module and the antenna, the transceiver units for both systems are placed as close as possible….

The UHF configuration for RECONSO will use a single deployable antenna module consisting of one dipole. The ISIS AntS antenna was selected for the purpose of providing sufficient omnidirectional signal coverage for data uplink. With regards to external placement, the selected configuration is advantageous in that the entire module of antennas is mounted to a single external face. In addition, to minimize interference from the satellite, it is desirable to place these antennas as far as possible from the CubeSat structure. With this in mind, and seeking to optimize the location of the antennas, the camera, and other external components such as the solar panels, the UHF antenna, like the NSL patch antenna, will be placed on the −X side of the CubeSat….

Electrical Interfaces

The Eyestar Duplex radio is the central electronic component of the subsystem. It connects to the NSL patch antenna with a 12 inch 50 Ω SMA coaxial cable, and sends data to the flight processor via a 9-pin micro D serial UART connection. Cabling specification for the serial cable is included in appendix A. The Tyvak UHF Transceiver component connects to the ISIS AntS dipole antenna with a 12-inch 50 Ω coaxial cable that has two female ends connecting the SMA output of the transceiver to the SSMCX input of the ISIS dipole. Additionally, the ISIS dipole system communicates directly with the flight processor via a 9-pin Omnetics cable carrying two I2C busses for deployment information and system status data [5].

Data Input/Output Interfaces

Data exchanges between the ground station and the RECONSO flight processor can occur along two separate pathways: the Globalstar system primary pathway and the auxiliary UHF pathway. Figure 1 illustrates the hardware and software path of the data as it moves from point to point.

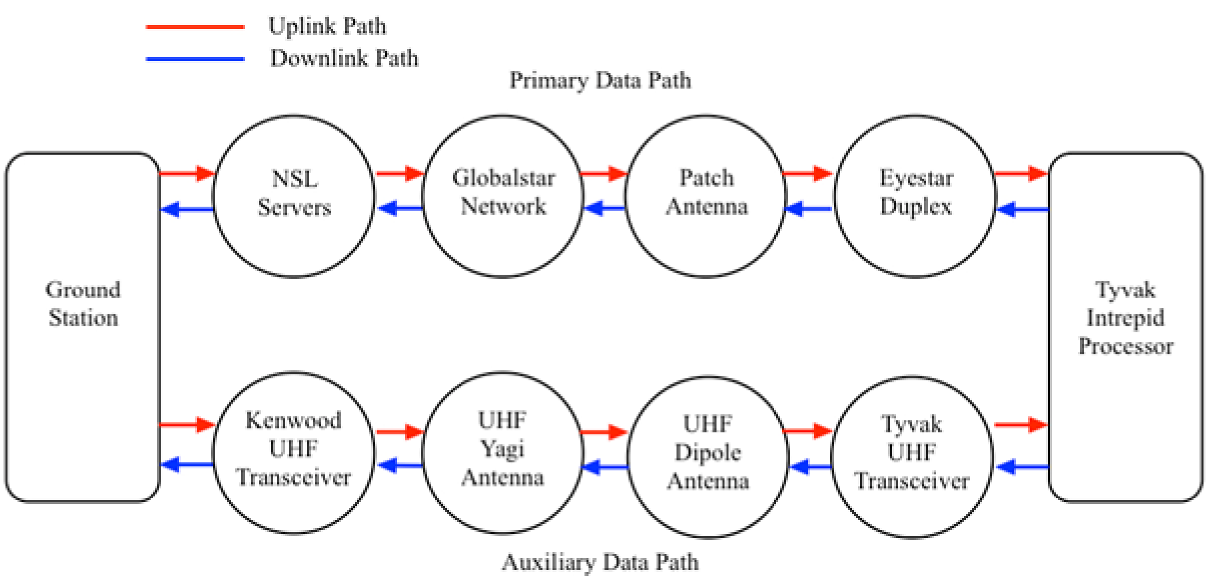

Figure 1. Data flow block diagram.

The UHF data communications system incorporates the AX.25 amateur radio packet protocol, Internet Protocol (IP) as a network layer, and User Datagram Protocol as a transport layer for network interfacing, but additional data protocols need to be defined. This protocol will be optimized for interfacing with the Core Flight Executive (cFE) software applications suite, which will govern all software exchanges and operations on the satellite. The Globalstar data communications system will function similarly, but all data will contain additional information that Near Space Launch uses to encode data transmissions to multiple satellites in orbit. Additional flight software routines will be required to extract data from the Globalstar packet format [5].

4.1.4 FSW

For hardware, the Tyvak Intrepid computer was chosen as the primary flight computer due to its compact design, low power requirements, internal sensors (3-axis gyroscope, magnetometer, accelerometer), fault tolerance, and peripheral communication interfaces. The Beaglebone Black was selected for the ADCS subsystem because it is commercially available and has a small size and mass.

From a software standpoint, NASA's Core Flight Executive (cFE) environment was chosen because it is platform independent and has a variety of application specific features that prove useful for spacecraft.

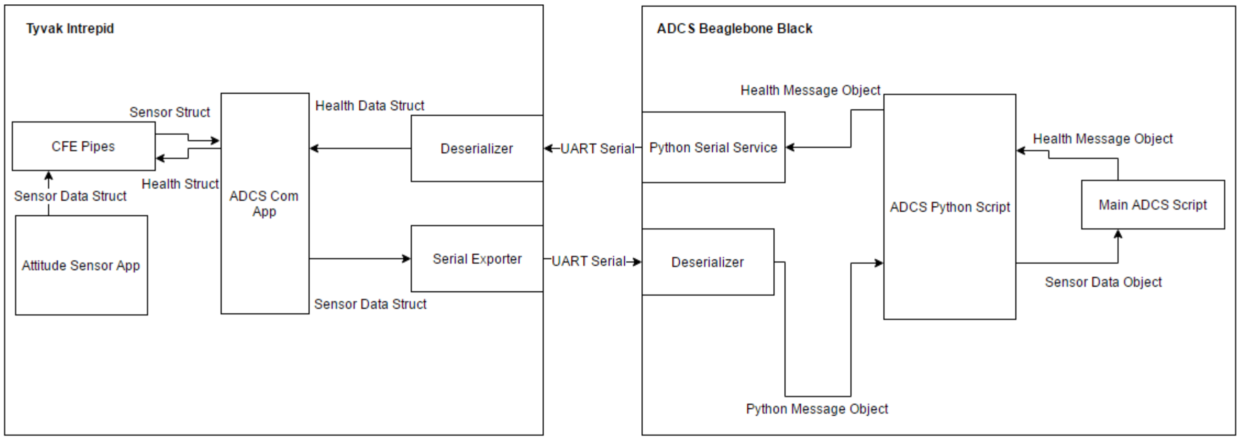

Figure 2. A block diagram showing the proposed interfaces of communication between the Tyvak Intrepid and the BeagleBone Black.

The requirements for the FSW subsystem state that data must flow two ways between the Tyvak Intrepid and the ADCS BeagleBone Black. The Tyvak will collect sensor data in a separate CFE app and pass the data in the form of a C struct to the cFE pipe messaging system, where the ADCS Communication App will collect the message object and export it to the ADCS subsystem via a UART serial port. The ADCS script will read the packaged sensor data and deserialize it, placing all relevant data into a python data object sent to the main ADCS script responsible for handling nominal operation of the ADCS subsystem.

The Main ADCS Script will send health data to the ADCS Messaging script which will pass the data object to a separate python serial script that will send the health data over a separate UART serial port. The health data will be read on the Tyvak and deserialized into a C data struct that can then be sent into the cFE pipe messaging system where any other cFE app can read the data and process it accordingly.

Note that both the Main ADCS script and the Attitude Sensor Monitoring App are external to the proposed scope of the project and will likely be handled by RECONSO members outside of the senior design team. Additionally, commands sent to the ADCS subsystem will not be handled by this proposed structure.

Currently, not much is known about the nature of the serial exporter component on the Tyvak. Most of the proposed structure is subject to change as problems arise, or more elegant solutions are found.

4.2 Codes and Standards

Given that the satellite is a CubeSat, it must closely conform to CubeSat standards in order to fit into a launch vehicle and deploy properly once in space. Of particular importance is the size restriction, which states that the entire satellite's dimensions must be multiples of 10x10x11.35 cm units [6]. Additional restrictions are placed on the satellite's mass, requiring that the entire satellite weigh less than 6 kg. The RECONSO satellite is a 6U satellite, meaning there is limited space and mass to work with.

Given that most of the team's relevant subsystems are not mechanically oriented, the size restriction has little impact other than limiting the computing devices used. In this way, it would not be viable to use a commercially available laptop as the flight control system due to size restrictions. The Tyvak Intrepid was chosen partially because of its small size, as was the Beaglebone Black.

Given that the UHF radio system uses amateur frequencies, it must comply with regulations regarding those frequencies. Furthermore, the UHF system will use the AX.25, IP, and UDP as the respective L2, L3, and L4 networking protocols for communications.

4.3 Constraints, Alternatives, and Tradeoffs

It has previously been determined by RECONSO that the satellite's communications modules will be an UHF radio as well as a Globalstar module. The Globalstar module was chosen as it simplifies data transfer, as "instead of transferring data from the ground station during the flyover window, the GlobalStar network of communications satellite in order would allow for data uplink and downlink independent of the ground station access window" [7]. The Globalstar system has been chosen as the primary mission communications module, but "given the heritage of the Georgia Tech ground station, a UHF system has also been included with the satellite as an auxiliary data transfer system"[7]. The UHF system was chosen over an S-band system as S-band transmitters are more expensive and have higher power requirements.

All electronics included in the satellite are expected to be relatively energy efficient so as to maximize the operational time of the satellite after each charge cycle. This means that computing performance is sacrificed in order to be energy efficient. Even so, extremely high performance is not necessary for mission tasks, so this should not be much of a problem.

Currently, the project is using many commercial off-the-shelf electronic components that are readily available and are not necessarily qualified for space. These components are much easier to obtain and require less time to develop for the project. Additionally, due to the mission’s relatively short length and the projected Low Earth Orbit, the electronics should not be exposed to a large amount of ionizing radiation [8], meaning they should last the length of the mission with few problems.

5. Schedule, Tasks, and Milestones

A Gantt chart showing the overall timeline for the project is included in Appendix A. A Pert chart showing the most-likely, optimistic and pessimistic times to complete each task is contained in Appendix B. The critical path for the project is bolded. Because most of the tasks could be completed in parallel, it is only 35 days.

6. Project Demonstration

The project as a whole will be demonstrated during Pre-Integration Readiness tests (PIR) mandated by the Air Force Research Lab (AFRL) in the fall semester. There are four tests: the Complete Charge Cycle Test, Simulated Comms Test, Command Execution Test, and the Day in the Life Test. These tests help ensure the satellite is ready for launch and is capable of functioning autonomously for extended amounts of time.

Of particular importance to the senior design team are the Simulated Comms, Command Execution, and the Day in the Life Tests as they involve the CDH, COMMS, and FSW subsystems. The exact requirements for these tests have not been shared with the senior design team yet, but more information will be provided in the future before they take place next semester.

7. Cost Analysis

As the RECONSO satellite is currently planned to be a one-off design and launch, costs are calculated for the production of only one unit.

Furthermore, since the senior design team is joining an already existing project at a late stage, all of the parts that the CD&H, COMMS, and FSW subsystems require have already been determined, ordered, and delivered to the teams. As the team is not responsible for procuring any hardware, those costs have not been calculated. Thus, the only costs directly associated with the project is the cost of the labor that we plan to contribute.

Labor costs have been calculated using a median starting salary of $70,000 per year [9]. All estimated labor times are listed in table 5.

Table 6. Overall labor costs of the project.

Task	Hours	Labor Cost
CDH	98	$3,430
Breakout board	15	$525
Harnessing	10	$350
Buildroot	15	$525
Software deployment	25	$875
SPI Connections	8	$280
EGSE Connection	30	$1050
COMMS	90	$3150
UHF System	25	$875
Globalstar System	15	$525
Communications software	50	$1750
FSW	80	$2,800
ADCS Script	20	$700
cFE App	60	$2,100
Total	268	$9,380

8. References

[1] M. Brown. (2012, March 12). Orbital Debris FAQ [Online]. Available: http://orbitaldebris.jsc.nasa.gov/faqs.html

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