Modular Infrastructure for Rapid Flight Software Development

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Overview

• Background
• Flight Software Development Process
• Simulink Model Overview
• Integration with cFE
Background

• Small Spacecraft Investigation
  – Modular CommonBus Spacecraft
• Hover Test Vehicle (HTV) Development
• Next Step - Lunar Atmosphere and Dust Environment Experiment (LADEE)
  – Joint ARC/GSFC Mission
  – Lunar Orbiter, Launch 2012
Flight Software Infrastructure Development

• Model Based Approach for Application Unique Software

• Latest Developments
  – Mathworks Simulink/RTW Embedded Coder
  – Integration of GSFC ITOS GDS Tool
  – Integration of GSFC Core Flight Executive (cFE)
  – Demonstrated on HTV
Flight Software Development Process Overview
FSW Process Overview

- Model Based Development Approach
  - Develop Models of FSW, Vehicle, and Environment in Simulink
  - Automatically generate Software using RTW/EC.
  - Integrate with hand-written and heritage software.
  - Iterate while increasing fidelity of tests – Workstation Sim (WSIM), Processor-In-The-Loop (PIL), Hardware-in-the-Loop (HIL)
Automatic Code Generation

- Simulink supports two way trace-ability between models and generated code
- Code Easy to read, well commented
Simulink Model Overview
Simulink HTV Architecture

FSW Auto-Coded and integrated with CFE
Simulink FSW Model

Command Processing:
- Receives commands via CDH (TCP/IP or RS422).
- Compiled in script allows flexible sequencing.
- Processes and Sets Control Modes.

Vehicle Health Monitoring:
- Command Checking
- Sensor Limit Checking
- Hardware status

State Estimation:
- Receives sensor data.
- Low Pass Filters
- Auto generated Kalman Filter.

Telemetry:
Passes data to the CDH so that it can be transmitted via TCP/IP or RS422.

Simulink Bus Creator

Prop Management:
- Fires thrusters based on commands and control mode.

GN&C:
- Guidance System sets desired angles based on position error.
- Guidance System maintains desired vertical velocity.
- Control System uses Bang-Bang approach to maintain desired angle.
Simulink Flight Hardware Model

Thruster dynamic forces and torques.

Mass and Inertia Characteristics of Vehicle

Sensor Models
- Analogs (Temperature, Pressure)
- LN200 IMU
- VIZ Camera System
Simulink Environment Model

- Command and Downlink Delays
- 6DOF Position and Rotational Propagation
- External Forces on Vehicle (Tether, platform)
- Gravitational Forces
- Vehicle Initial Conditions
cFE Simulink Integration
cFE – Core Flight Executive

- Goddard Space Flight Center Developed
- Derived from Legacy Missions
- Flexible infrastructure for Space Flight Software

- Components:
  - Executive Services
  - Event Services
  - Time Services
  - Table Services
  - Software Bus Services
cFE Simulink Development Goals

- Utilize cFE with no changes
- Automate process during Code Generation.
- Subsystem Blocks generate to cFE Applications that run at desired rates
- Simulink Apps/Blocks Communicate via cFE Software Bus
Layered Architecture Approach

Payload Manager, GN&C, Thermal, State Estimation, Propulsion Management, Telemetry, Power, Vehicle Health and Monitoring, Command Processing

Simulink Generated Mission Unique Application Layer

Cmd Ingest, Telem Output, HW I/O, File Mgmt, Memory Mgmt, House Keeping, Master Timer

Generic Services Layer (GSFC cFS) & Hand Code

Table Management, Software Bus, Exec & Task Services, Time Management, Event Handler

System Support Layer (GSFC cFE)

VxWorks OS, Bootstrap Loader, Memory R/W Driver, Timer Driver, PCI Driver, MOAB Driver

OS Services Layer (VxWorks OS, GSFC OS Abstraction Layer)

Processor BRE 440, Non-Volatile Memory, Volatile Memory, Timers, Comm.

Physical (Hardware) Layer

Analog Acquisition, cPCI, RS-422, Digital I/O
cFE Simulink Key Ideas

• Modular Tasks (vs. Monolythic)
  – Pros:
    • More Flexible
    • Simplifies Task Replacement
    • Easier Debugging – can look at messages between tasks
  – Cons:
    • Harder to implement
    • More overhead due to more tasks and messages

• Mathworks Template (TLC) File
  – Executed during Code Generation Process
  – Allows customization of created code
  – Leveraged to autocode cFE Apps from Simulink
cFE Simulink Implementation

• Simulink Bus translates to cFE Message
• RTW/EC generates Task Description
• Master Timer Generates “Tick” to Schedule Apps and generate Output Messages
• Receive Structure Msgs update local App Input Values
• Apps also Respond to Other Command and Housekeeping Messages
cFE Simulink Autocode Process

RTW/EC

- Sequencer
- VHM
- State Est.
- Thermal
- Payload
- Prop Pyro
- Power
- GN&C
- Telemetry

Compile & Link

- Sequencer.c + IF.h
- VHM.c + IF.h
- State_Est.c + IF.h
- Thermal.c + IF.h
- Payload.c + IF.h
- Prop_Pyro.c + IF.h
- Power.c + IF.h
- GNC.c + IF.h
- Telemetry.c + IF.h

FSW

- HC_Module.c
- CFE_inteface.c
- Drivers.c

HTV Bus Description

ITOS DBX
Simulink Bus becomes cFE Message

'ins_msg', ...
''', ...
sprintf(''), { 
  {'ins_delta_velocity_counts', 3, 'int16', -1, 'real', 'Sample'}; ...
  {'ins_delta_angle_counts', 3, 'int16', -1, 'real', 'Sample'}; ...
  {'ins_status', 1, 'int16', -1, 'real', 'Sample'}; ...
  {'ins_mode', 1, 'int16', -1, 'real', 'Sample'}; ...
  {'ins_data', 1, 'int16', -1, 'real', 'Sample'}; ...
  {'ins_counts', 3, 'int16', -1, 'real', 'Sample'}; ...
  {'ins_checksum', 1, 'int16', -1, 'real', 'Sample'}; ...
} ...
cFE Simulink App Loop

```
Struct App_Inputs In
Struct App_Outputs Out
App_Init() {
    Initialize_App_Inputs()
    Subscribe_SB_Msgs(Tick, AppMsgs,...)
    Simulink_Init(In, Out)
}
App_Main(){
    App_Init()
    while(1) {
        sb_receive_msg(msg, timeout)
        if (msg == tick) {
            Simulink_Step(dt, In, Out)
            sb_send_msg(Out) /* app update */
        } else {
            If (msg == app_update) /* Process other App Msgs */
            App_Update_Inputs(msg, Out)
            else Process_Msg(msg) /* HK, Cmds, etc… */
        }
    }
}
```
New Efforts

- 3DOF Simulator
- Command Queueing
- Parameter Tables
- Command & Telemetry Dictionary - XTCE
- Snapshot/Snapshot Recall
- Latency Reduction
  - Output Message triggers “Step” of Next Module
  - Retains Modularity
Summary

- NASA Ames developing infrastructure for rapid flight software development
- Model based process leverages Mathworks Simulink, RTW-EC
- Developed modular approach to integrate auto-generated code with GSFC’s cFE.
- Successfully demonstrated on HTV
- Being Utilized on NASA’s LADEE mission
Backup
cFE IMU App Loop

IMU_Main(){
    while(1) {
        struct imu_input_str imu_in
        read_msg_que(imu_in, timeout) /* VxWorks Msg Que */
        sb_send_msg(imu_msg)
        Send_tick()
    }
}

Cnt = 0;
Send_tick() {
    sb_send_msg(400HZ_Tick)    /* Do we need 400HZ Tick or key off of IMU Data? */
    if ((Cnt % 2) == 0)     sb_send_msg(200HZ_Tick)
    if ((Cnt % 4) == 0)     sb_send_msg(100HZ_Tick)
    if ((Cnt % 40) == 0)   sb_send_msg(10HZ_Tick)
    if ((Cnt % 400) == 0) sb_send_msg(1HZ_Tick)

    Cnt++;
}

/* Note: Other Apps same as IMU without the Send_tick() */
Workstation Simulation

- Simulink/SystemBuild Only (No Autocode)
- Early in development process
- Algorithm Development
- Requirements Analysis
Processor-in-the-Loop Simulation

• Models autocoded and running on RT processors
• Inexpensive “flight-like” processor
• Tests autocoding process & integration with C&DH software
• Integration with Telemetry Software allows early development/testing of downlink
• Can be used for initial code size and resource utilization analysis
Hardware-in-the-Loop Simulation

- Flight code runs on Flight Avionics EDU
- Provides testing of FSW with Avionics I/O
- Definitive answers on resource utilization
- Highest fidelity simulations for verification/validation
Motivation for Moving to Simulink

- Industry appears to be moving that direction.
- Mathworks Extensive support network.
- Mathworks tools for Requirements management, Documentation, and V&V.
- Bus concept makes model management easier.
- Monolithic SystemBuild models not conducive to Reuse and V&V.