Use of SPARK in a Resource Constrained Embedded System

Chad Loseby
Peter C. Chapin
Carl Brandon

Vermont Technical College
Outline

- Overall Problem
- Ice Buoy Requirements
- Our Solution Using SPARK/Ada
- Lessons Learned
- Future Work
Sea Ice Dynamics

• Desire to understand the dynamics of Arctic sea ice
  – Jun Yu (University of Vermont) has been developing mathematical models.
  – Used satellite obtained data of ice movement, deformation, and thickness.
  – Needs ground truth information.
    • Wind
    • Temperature

• VTC's role?
General Requirements

- Must tolerate spring conditions in arctic
  - Temperatures down to -20 C
  - Wind, rain, ice (not much snow)
  - Animals
- Must operate for ~3 months
- Will not be retrieved
  - Must transmit data to base via satellite link
Data Requirements

• Each sample contains...
  - GPS location
  - Wind speed
  - Relative wind direction
  - Temperature
  - 3-axis magnetometer reading
    • Together with location allows absolute orientation to be computed.

• Each data item separately time stamped
Software Requirements

• Sampling Frequency
  – Very slow... once every 30 minutes
    • Software performance not an issue
    • No significant real-time requirements

• Accuracy
  – Spacial resolution: 100s of feet
  – Temporal resolution: minutes
  – Data accuracy: 10-20%
Reliability

- Significant requirements
  - No access once deployed
  - No ability to upload fixes
  - Device entirely autonomous
  - Must recover from intermittent hardware failure

- Keep it simple
  - No on board processing of data
CubeSat Platform

- MSP430 based
  - Very low power
  - Adequate performance
  - Highly constrained
    - 60 KiB ROM
    - 2 KiB RAM
- Used for future projects
Wind Speed

Wind Direction

Magnetic Bearing

Temperature

CubeSat MSP430

Satellite Modem

Provides GPS Location and Time
Software Structure

- Initialize
- Sleep
- Gather Data
- Report Data

Data Buffers
Software

- SPARK/Ada
  - Problem...
    - No Ada compiler for CubeSat platform
  - Solution...
    - Compile Ada to C, then use C compiler
Tool Chain

- Ada Main
  - SPARK
    - Ada Magic
      - C Main
      - CrossWorks
        - MSP 430 Object Code
  - C Low Level

Information flow analysis
SPARK Provides

- More reliable software
- A way to simplify the run time system
  - Exception support not needed
    - Program_Error can't occur
    - Constraint_Error can be avoided
  - Dynamic memory allocation not needed
  - Lack of dynamic memory also makes evaluating memory consumption easier
- *We didn't use any run time system!*
C as Assembly Language

• Need C for low level access
  – Ada Magic compiler does not know the platform.
• Minimize the amount of C
  – C is error prone
  – C is not visible to SPARK
• We kept our C functions one or two lines.
package Timer
  --# own Hardware;
is
  procedure Initialize;
  --# global out Hardware;
  --# derives Hardware from ;
pragma Import(C, Initialize);

procedure Sleep;
  --# global in out Hardware;
  --# derives Hardware from Hardware
pragma Import(C, Sleep);
end Timer;
Hand Written C

- Platform specific code written in C
  - ... Interacts with target C compiler
  - ... Uses names compatible with Ada Magic generated code

```c
#include <msp430x14x.h>
#include <standard.h>

void Timer_Sleep(void)
{
    _BIS_SR(LPM3_bits);
}
```
Other Hardware

- A similar technique was used for
  - Interfacing to A/D converters
  - Interfacing to USARTs
  - Interfacing to debugging LEDs
- Interrupt service routines in C
  - But we only used one (for the timer)
    - Used to wake up the system.
  - USART I/O was done with polling!
Results

- It is possible to compile Ada onto a very small device using C as an intermediate language.

- **SPARK helps by enabling massive run time simplifications.**

- It is possible to build such a system in an educational setting.
Future Work

• Finish prototype
  – Still need to complete enclosure
  – Still need to complete software
    • Data formatting
    • Verify freedom from run time errors
    • Evaluate memory consumption
    • Prove buffers can be drained
  – Plan to do live tests this winter in Vermont

• Deploy in March 2011?
QUESTIONS?

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