How a Lightweight RTOS can Drive CubeSat Flight Software

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Flight Software Requirements

- Reliable - Duh
- Modular – so that multiple coders can work on it simultaneously
- (Re-)configurable – e.g. for testing, or to optimize performance
- Efficient – use a minimum of RAM, Flash, power
- Fast – satisfy responsiveness & throughput requirements
- Capable – permit the use of (all) of the MCU’s hardware / peripherals, without getting in the way
- Clean – enable a consistent programming methodology
What is an RTOS?

• A chunk of software that:
  • Has a well-defined API, clear documentation, etc.
  • Provides a variety of services to build an application on top of it:
    • Scheduling
    • Multitasking
    • Time-based services
    • Inter-process communications
  • Has ‘soft” or “hard” real-time performance
  • Is configurable, extensible, etc.
  • Has a user base of > 1

• Pumpkin’s Salvo™ RTOS is a lightweight RTOS designed for embedded MCUs (MSP430, PIC, C8051, etc.)
Non-RTOS vs RTOS Coding

• Non-RTOS applications:
  • Are typically very linear in their coding and execution
  • Typically don’t have scheduling, priorities, etc.
  • Their run-time performance is typically strongly affected by additions / deletions to the code
  • Must often utilize interrupts heavily to achieve a modicum of responsiveness
  • Are initially smaller … but eventually become larger than the RTOS equivalent

• RTOS applications
  • Are very loosely-coupled
  • Leverage multitasking, priorities and scheduling to maximize responsiveness, minimize load and reduce power consumption
  • Concentrate functionality via a few modules, ultimately reducing code size
  • Have a very consistent look and feel to the code
Who uses (Embedded) RTOSes?

- Some Salvo RTOS applications:
  - Automated shrimp feeders in Patagonia
  - Industrial process controls
  - Health / fitness monitors
  - SDL’s DICE mission
  - Sports watches
  - Bowling lanes
  - Electronic toys
  - Geotagging devices
  - Earth science sensors
  - SSDL’s LMRST-Sat mission
  - All of Pumpkin’s sub-Linux-size embedded controllers
Multitasking

OSInit();

OSCreateTask(task_cmd_do, TASK_CMD_P, 2);
OSCreateTask(task_scpi, TASK_SCPI_P, 1);
OSCreateTask(task_status, TASK_STATUS_P, 3);
OSCreateTask(task_led, TASK_LED_P, 15);
OSCreateTask(task_self_test, TASK_SELF_TEST_P, 5);
OSCreateTask(task_vinti7, TASK_VINTI7_P, 8);

while (1) {
    OSSched();
}

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void task_TAP_EPS_temperature(void) {

    TAP_set_name(TAP_ID_EPS_TEMPERATURE, "EPS temperature");
    TAP_set_interval(TAP_ID_EPS_TEMPERATURE,
        TAP_ID_EPS_TEMPERATURE_INTERVAL_DEFAULT);
    TAP_set_size(TAP_ID_EPS_TEMPERATURE,
        SIZEOF_TAP_ID_EPS_TELEM_TEMPERATURE);
    TAP_set_action(TAP_ID_EPS_TEMPERATURE, SEND_TAP_SDCARD);
    TAP_set_carton_fn(TAP_ID_EPS_TEMPERATURE,
        carton_EPS_temperature_fill_TAP);

    while(1) {
        OS_DelayTS(TAP_get_interval(TAP_ID_EPS_TEMPERATURE));
        TAP_push_TAP(TAP_ID_EPS_TEMPERATURE);
        WDT_inc_counter(TAP_ID_EPS_TEMPERATURE);
    }
}
Waiting with a Timeout

```c
void task_GPS_timeout(void) {
    while(1) {
        OS_WaitBinSem(BINSEM_GPS_TIMEOUT_S_P, OSNO_TIMEOUT);
        OSTryBinSem(BINSEM_GPS_TIMEOUT_E_P);
        OS_WaitBinSem(BINSEM_GPS_TIMEOUT_E_P, GPS_TIMEOUT_TIME);
        if(OSTimedOut()) {
            gps_power(0);
        }
    }
}
```
char * time_elapsed_DDHHMMSSTT(void) {
    OSTypeTick sec, tt;
    int dd, hh, mm, ss;
    static char str[15];

    tt = OSGetTicks();
    sec = (tt / TICKS_PER_SEC);
    dd = (sec / SEC_PER_DAY);
    hh = (sec / SEC_PER_HOUR)
        - (dd * HOUR_PER_DAY);
    mm = (sec / SEC_PER_MIN)
        - (hh * MIN_PER_HOUR) - (dd * MIN_PER_DAY);
    ss = sec - (mm * SEC_PER_MIN)
        - (hh * SEC_PER_HOUR) - (dd * SEC_PER_DAY);
    tt = tt%TICKS_PER_SEC;
    dd %= 100;
    sprintf(str, "%02d:%02d:%02d:%02d.%02d", dd, hh, mm, ss, tt);

    return str;
}
void time_ISR_TimerA0(void) __interrupt[TIMERA0_VECTOR] {
    TACCR0 += SYSTEM_TICK_10ms;
    OSTimer();

    ...
}

All it takes is one API call …
ISR-to-task Communications

```c
void task_cmd_do(void) {
    unsigned char cmd;

    while (1) {
        OS_WaitSem(SEM_CMD_CHAR_P, OSNO_TIMEOUT);
        if ((cmd = uart1_getchar())) {
            switch (tolower(cmd)) {
                // Help.
                case 'h': case '?':
                    cmd_explain();
                    break;
                ...
            }
        }
    }

    void __attribute__((interrupt,no_auto_psv)) _U1RXInterrupt(void) {
        uart1_inchar(ReadUART1());
        OSSignalSem(SEM_CMD_CHAR_P);
    }
}```
Sleeping whenever Possible

```c
void OSIdlingHook(void) {
    asm(" PWRSAV #1 ");
}
```
int main() {
    init();
    i2c1_init();
    I2C1_Msgs_Received = 0;
    SCPI_Init(&scpi_context);
    scpi_cmds = 0;

    [SNIP]

    while (1) {
        if(I2C1_Msgs_Pending) {
            //SCPI MESSAGE RECEIVED
            OSSignalBinSem(BINSEM_SCPI_RCVD_P);
        }
        if(I2C1STATbits.I2COV) {
            //I2C OVERFLOW -- CLEAR AND RESET I2C1
            i2c1_init();
        }
        OSSched();
    }
}
Lightweight Footprint

Pumpkin GPSRM 1 v0.3.9 Flash Memory Utilization
(PIC24EP256MC206 w/262,144 bytes Flash)

- Pumpkin GPSRM utility functions [478]
- Microchip 16-bit self-test functions [1066]
- Pumpkin SupMCU utility functions [1250]
- Miscellaneous functions [1294]
- Pumpkin UART1 & UART2 library [1364]
- init(), main() & tasks [2318]
- Pumpkin Salvo RTOS [2360]
- SCPI Command Processing [9816]
- Vinti7 Orbit propagator [27734]
- C library functions [48353]
- Free [166111]
Conclusion

- Pumpkin’s lightweight Salvo RTOS has been used as the basis for flight software on multiple successful CubeSat missions
- A well-designed lightweight RTOS
  - Can have minimal impact on Flash and RAM
  - Can be exceptionally robust (see spaceflight heritage), in part because of its simplicity
  - Provides a wealth of useful features
  - Is conducive to team-based software development
  - Does not “get in the way” of real-time performance
Q&A Session

Thank you for attending this Pumpkin presentation at the 2015 CubeSat Developers’ Summer Workshop!
Notice

This presentation is available online at:

Appendix

• Speaker information
  - Dr. Kalman is Pumpkin's president and chief technology architect. He entered the embedded programming world in the mid-1980's. After co-founding Euphonix, Inc – the pioneering Silicon Valley high-tech pro-audio company – he founded Pumpkin, Inc. to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He is the creator of the Salvo RTOS and the CubeSat Kit. He holds several United States patents. He is a consulting professor in the Department of Aeronautics & Astronautics at Stanford University and directs the department’s Space Systems Development Laboratory (SSDL). Contact Andrew at aek@pumpkininc.com.

• Acknowledgements
  - Pumpkin’s Salvo, CubeSat Kit, MISC and SUPERNOVA customers, whose real-world experience with our products helps us continually improve and innovate.

• CubeSat Kit information
  - More information on Pumpkin’s CubeSat Kit can be found at http://www.cubesatkit.com/. Patented and Patents pending.

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