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EMBEDDED SYSTEMS CONFERENCE '15
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UBM

Rapid Application Development with Embedded Lua

James Snyder, Board Member and Core Developer, eLua Project

Traditional Tools

- Development Suite
  - Large footprint, not always cross-platform
  - Free options are vendor-specific
- Language
  - ASM, C, C++
- Development cycle
  - Compile, Flash, Test/Run

Traditional Tools

Disadvantages

- Steep learning curve
- Portability
- Code complexity

Advantages

- Low-level access/control
- Deterministic behavior
- Performance

New Traditional Tools: mbed

- Development Suite
  - Online IDE/compiler, local IDE/compiler
- Language
  - C, C++ with cross-platform HAL, networking, components, etc..
- Development cycle
  - Compile, Download, Copy, Test/Run

Alternative

- Development Environment
  - Self-hosted, local IDE or RPC
- Language
  - High level, cross platform with HAL
  - Easy to extend in C
- Development cycle
  - Type, hit enter, see result – compiler is on the MCU

Disadvantages

- Performance
- High memory usage
- Dynamic memory allocation
- Non-deterministic execution time
  - Virtual Machine with Garbage Collection
  - Interrupts handled with VM-scheduled queuing

Advantages

- Performance
- Low barrier to get started / shallow learning curve
- Interactive development and debugging
- Update behavior/logic without re-flash
- Easy end user or integrator customization

Disadvantages?

Performance & Memory

- 32-bit MCUs
  - Inexpensive
  - Fast
  - Lots of SRAM + external mem

Determinism & Dyn. Allocation

- Some applications are out:
  - ECUs and other Real-Time
- Lots of applications where it doesn't matter

Options

- Lua
  - eLua
- Squirrel
  - Electric Imp
- Python
  - MicroPython
  - Python On A Chip
  - SNAPpy
- FORTH
- JavaScript
  - Tessel
  - Espruino
- BASIC
  - BASIC Stamp
- BGScript (BlueGiga/SiLabs)

*Not all of these provide interactive programming

What is Lua?

- Powerful dynamic language
- Compact enough to run on a 32-bit microcontroller
- Written in ANSI C
- Simple, flexible C API
- Used for scripting in Photoshop Lightroom, numerous games and other tools

Syntax

- Types
  - nil, boolean, number, string, function, userdata, thread, table
  - All first class
  - Fundamental data structure is table

```
a = nil

b, c = true, 3.14159

d = "Hello " .. "World"

e = function () print("Hi!") end

f = coroutine.create(e)

g = {a=a,b=b,c=c,d=d,e=e}
g.f = f
```

Control Structures

if eliseif else

```
if a == 1 then
    print("1")
elseif a == 2 then
    print("2")
else
    print("error")
end
```

while

```
i = 1
while i <= 10 do
    print(i)
    i = i + 1
end
```

for

```
for i=1,10 do
    print(i)
end
```

```
t = { 1, 2, 3, 4,
5, 6}
for k in pairs(t)
do
    print(k)
end
```

break, return

```
for i=1,10 do
    if i = 5
then
        break
    end
end
```

```
function test (a,b)
    return a*2,b/2
end
```

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Closures

```
function newSquares ()
  local i = 2
  return function ()
           i = i*i
           return i
         end
end

square = newSquares()
print(square())
```

Co-routines

```
co = coroutine.create( function ()
        t = { 1, 2, 3, 4, 5, 6}
        for k in pairs(t) do
            print(k)
            coroutine.yield(k)
        end
    end)

coroutine.resume(co)
```

Learning Lua

- Learn Lua in 15 Minutes
  - http://tylerneylon.com/a/learn-lua/
- Programming in Lua
  - http://www.lua.org/pil/
- Reference Manual
  - http://www.lua.org/manual/5.1/

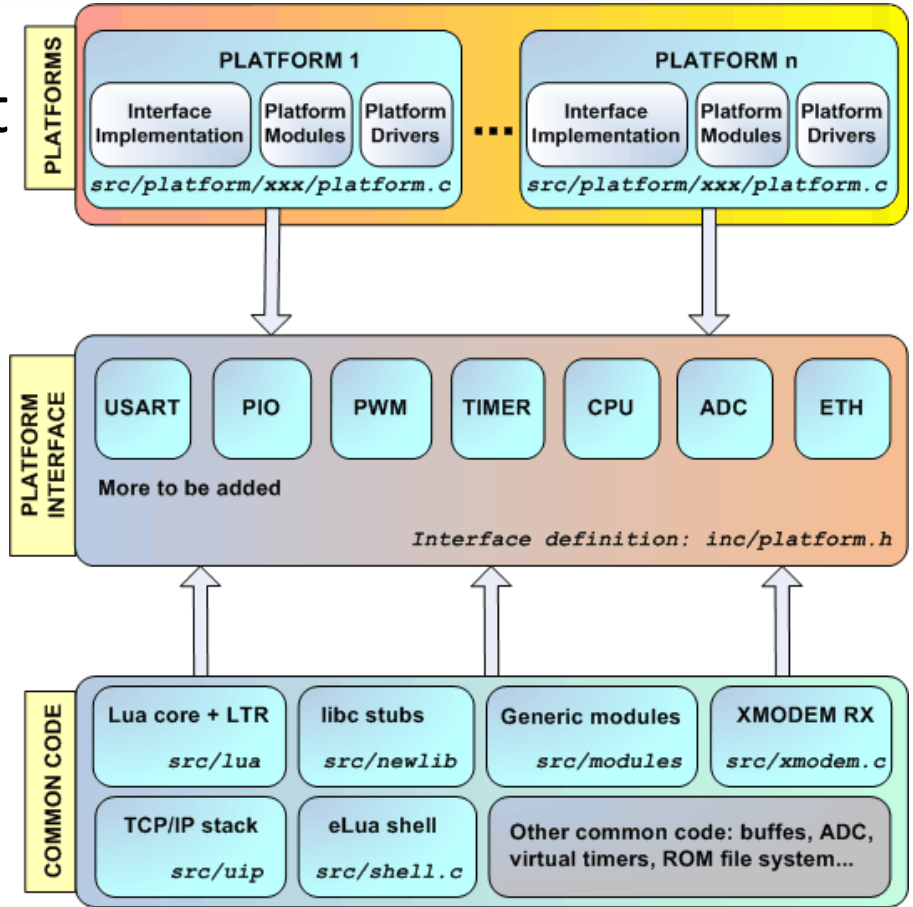
What is eLua

- Full implementation of Lua for microcontrollers
- Hardware Abstraction Layer (C & Lua APIs)
- Filesystem and hooking of system calls
- Added Lua modules (bit manipulation, byte packing, etc..)
- Permissively Licensed (MIT for Lua & eLua core)

Platform Support

HAL

Common Code



Lua Core Modifications

Lua 5.1.5

+ Emergency Garbage Collection
+ Read-only tables
+ Byte-code execution from flash
+ NaN packing for more efficient types
+ Integer-only support (64, 32-bit)

Supported Boards

- STM32F4DISCOVERY (master)
- NUCLEO-F401RE, NUCLEO-F411RE (master)
- Mizar32
- mbed (LPC1768)
- ET-STM32 Stamp
- Many others: http://www.eluaproject.net/overview/status

Common Code

- Filesystems
  - MCU Flash-based ROMFS & WOFS
  - SD/MMC over SPI with FatFS
  - Semihosting (MBED local mass storage over debug)
  - Remote Filesystem (over serial/network)
- Modules
  - bit manipulation, byte packing, rpc

Common Code

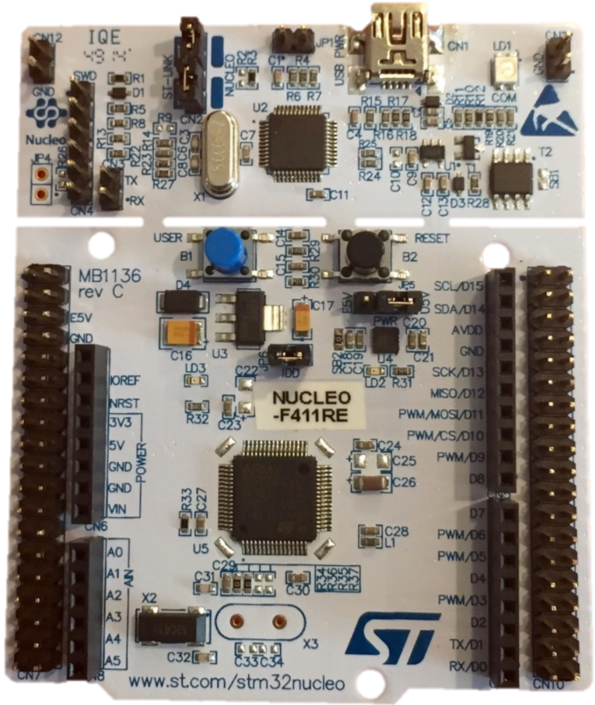
- Shell
  - start Lua
  - xmodem file transfer (recv)
  - filesystem interaction (ls, cp, cat, etc..)

Startup

- LuaRPC (if enabled)
- autorun.lua (if present)
- Shell (if enabled)
- Lua REPL

Getting Started

- Get a supported board
  - NUCLEO-F401RE
  - NUCELO-F411RE
- Generate a build:
  - http://builder.eluaproject.net/
- Download & copy bin file to mass storage
- Connect to Serial/COM port



Quick Demonstration

Example Project

- Lets blink some LEDs!
- WS2812B-based Neopixel LED array
  - Individually controllable RGB LEDs w/ 8-bits/channel brightness
  - Single-wire control using NZR protocol at 800 kHz
    - 24-bits/controller, GRB
      - 0=short high (~0.35 µs), long low (~0.8µs)
      - 1=long high (~0.7 µs), short low (~0.6µs)
    - ends with a reset (>=50 µs low)
  - Signals cascaded from controller to controller

Example Project

- Naïve implementation (bit bang)
  - Pure Lua not fast enough for GPIO toggling at 800 kHz update rate
  - Implement in C and provide a Lua API
  - Update algorithm & parameters on the fly

Code Available: http://github.com/jsnyder/elua-escbos

Live Demonstration

In The Field / Lab
(with some lessons learned)

Taming GhostBot

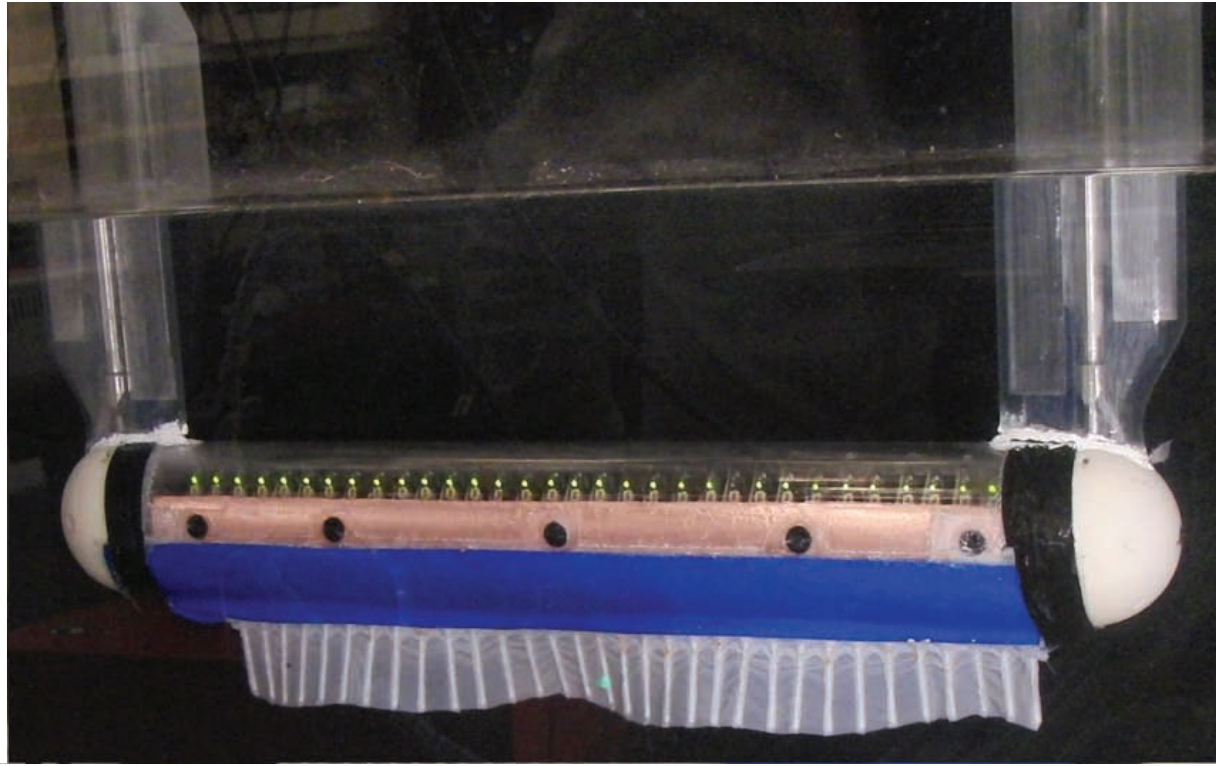


Image credit: NXR / MacIver Lab, Northwestern University

Lessons Learned / Implementation

- 32 independent rays, controllable over CAN at 100 Hz
- eLua provided a dynamic environment where parameters and code could be updated on the fly over LuaRPC
- Performance constrained doing emulated floating point on 72 MHz Cortex-M3 (STM32F1)
- Upgraded to a higher clock rate Cortex-M4 to provide more headroom (STM32F4)

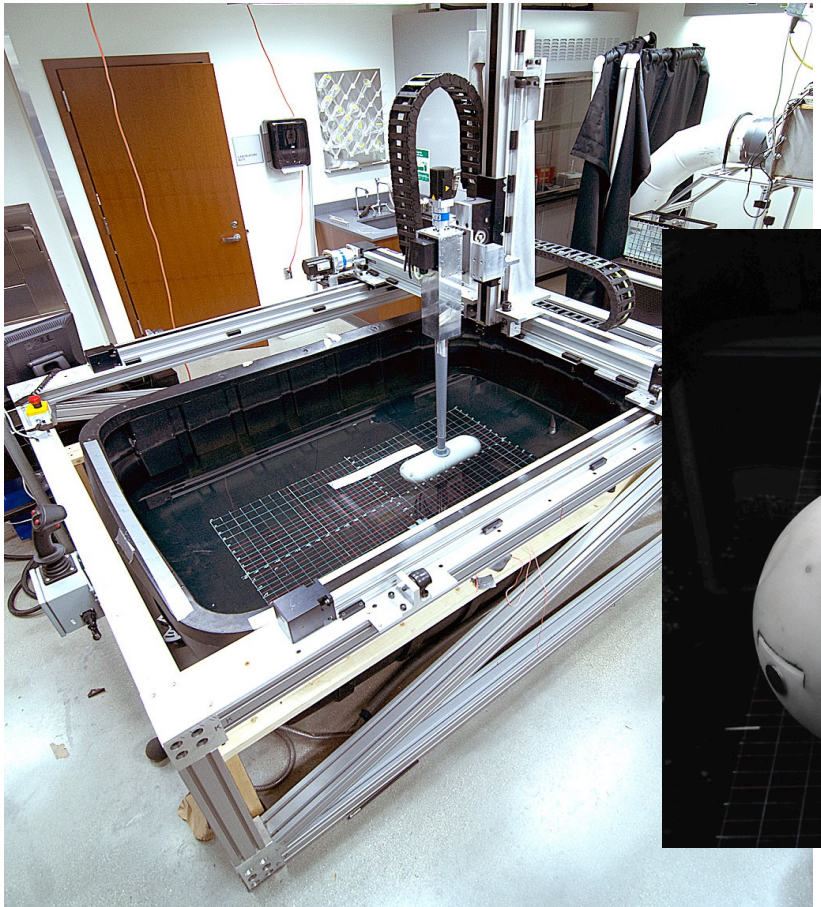
GhostBot Code Structure

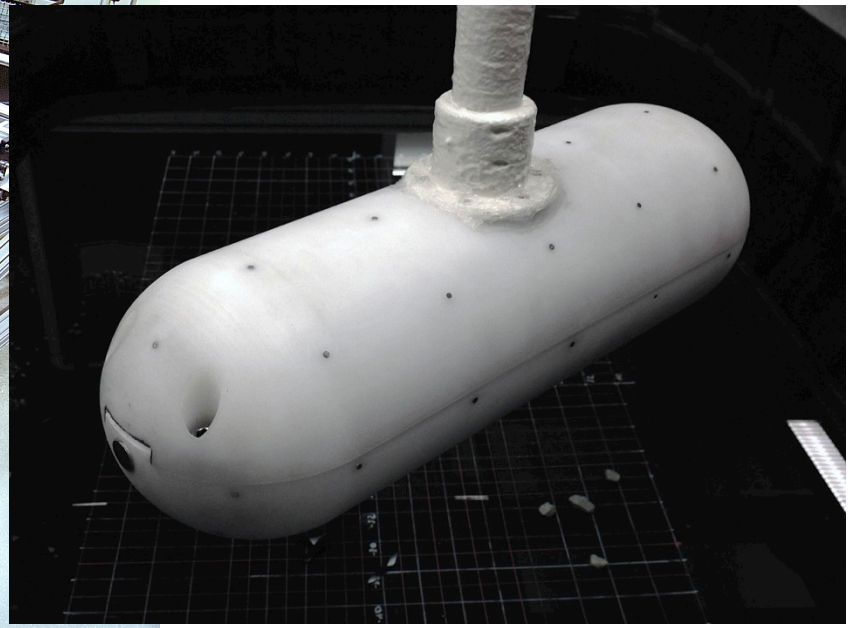
autorun.lua

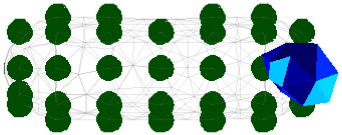
```
local state = {}
local start_time
local stimer = tmr.SYS_TIMER

cycletime = 10000

function control()
end

handle = rpc.listen(uart.CDC,0)
```

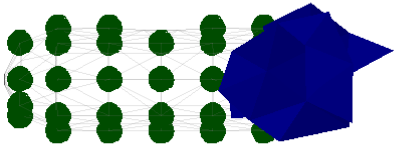
```
while true do
   -- get cycle start time
   start_time = tmr.read(stimer)
   -- Check for pending RPC request
   if rpc.peek( handle ) then
      rpc.dispatch( handle )
   end
   -- run control function
   control()
   -- wait until cycle time elapsed
   while tmr.getdiffnow( stimer, start_time ) < cycletime
do end
end
```

Imaging with Electricity



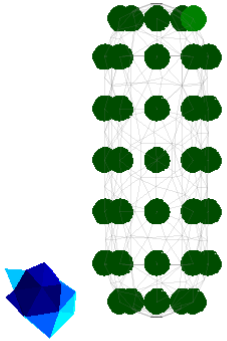


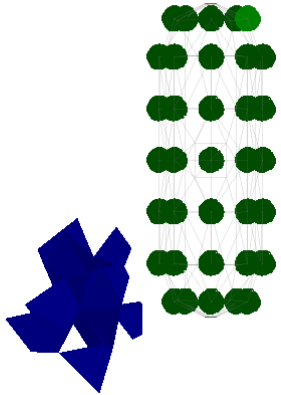


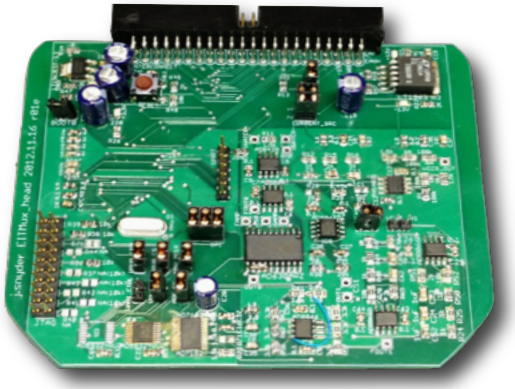


Simulated Insulating Object

Reconstructed Location/ Impedance





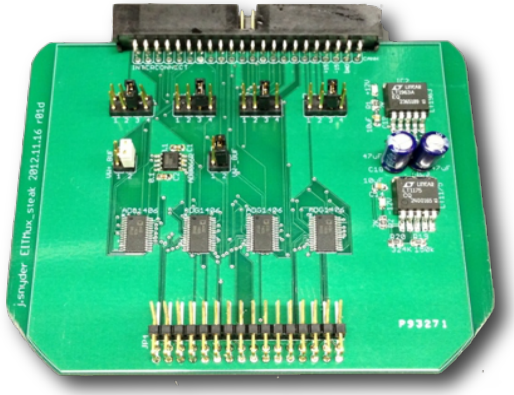


EITMux Head

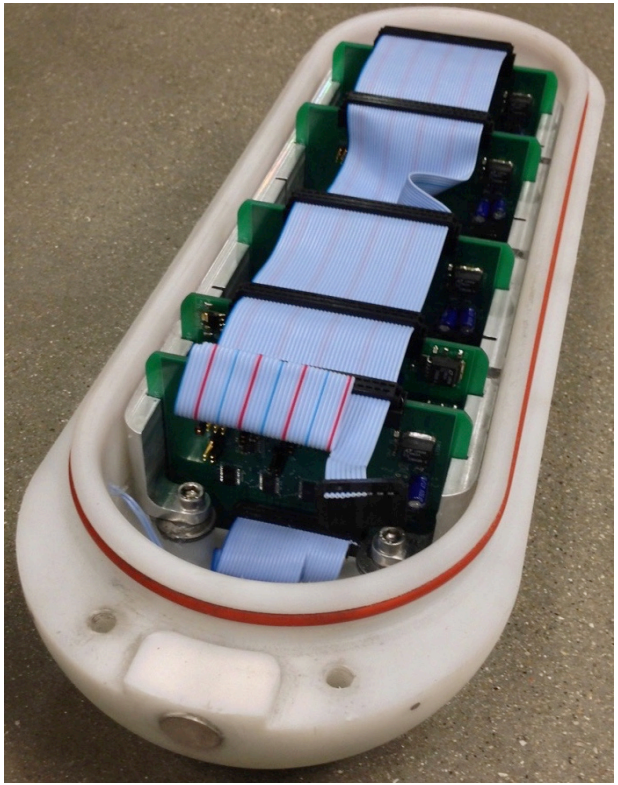
- STM32F4 running eLua with CAN interface
- Sinusoid Function Generator
- Voltage Controlled Current Source (VCCS)
- Lock-in amplifier / ADC

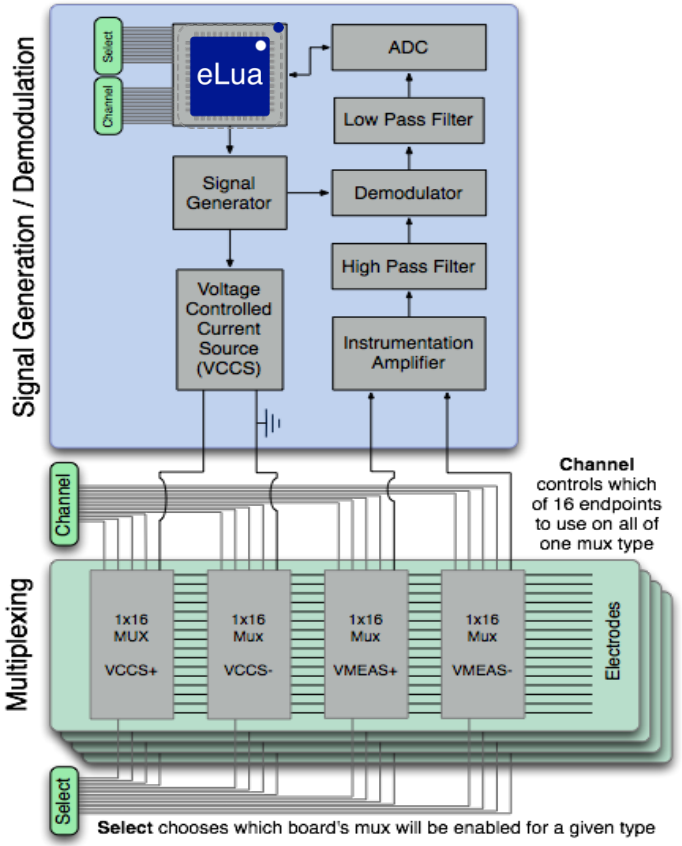
EITMux Steak

- 4x 1x16 multiplexers



x4




Signal Generation / Demodulation
Select
Channel
eLua
ADC
Low Pass Filter
Signal Generator
Demodulator
High Pass Filter
Voltage Controlled Current Source (VCCS)
Instrumentation Amplifier
Channel
Channel controls which of 16 endpoints to use on all of one mux type
Multiplexing
1x16 MUX VCCS+
1x16 Mux VCCS-
1x16 Mux VMEAS+
1x16 Mux VMEAS-
Electrodes
Select
Select chooses which board's mux will be enabled for a given type

Lessons Learned / Implementation

- No custom C modules, drivers for ADC & waveform generator implemented in Lua
- All Lua code non-blocking
- Deterministic timing by using ADC clock to drive system (400 Hz)
- Updated GPIO multiplexing & forwarded ADC samples over CAN

Code Structure

autorun.lua (stripped down)

```
function mux_pattern()
    while true do
        -- generate mux pattern
        coroutine.yield(brd_select, chan_select)
    end
end

co_mux_pattern = coroutine.create( mux_pattern )

spi.setup( 0, spi.MASTER, 1e6, 1, 1, 16 )
can.setup(0,1000000)
adc_setup()
function_generator_setup()
```

```
function gpio_negedge_handler( resnum )
    cpu.cli( cpu.INT_GPIO_NEGEDGE, SPI_MISO )

    status, brd_select, chan_select =
coroutine.resume( co_mux_pattern )

    if( chan_select ~= nil) then
      pio.port.setval( chan_select, pio.PE )
      pio.port.setval( brd_select, pio.PD )
    end

    adc_value = spi.readwrite( 0, 0x58FF, 0xFFFF )
    cpu.sei( cpu.INT_GPIO_NEGEDGE, SPI_MISO )
end

-- continues on next slide...
```

Code Structure

```
while true do
    can, canidtype, message = can.recv()
    if candid ~= nil then
        if canid == MSG_TYPE_FREQ_SET then
            -- update frequency
        elseif canid == MSG_TYPE_PARAM_REQ then
            -- send back value for parameter
        elseif canid == MSG_TYPE_PARAM_SET then
            -- update parameter
        elseif canid == MSG_TYPE_UPDATE_REQUEST then
            -- return data data
        else
            if DEBUG then io.write( string.format("unknown msg id: %d\n", canid ) ) end
        end
    end
end
```

Scriptable Satellite Tracking

GSatMicro

- Compact Iridium tracker
- GPS, accelerometer, magnetometer
- RS-232, USB & Bluetooth Low Energy interfaces
- http://www.gsatmicro.com

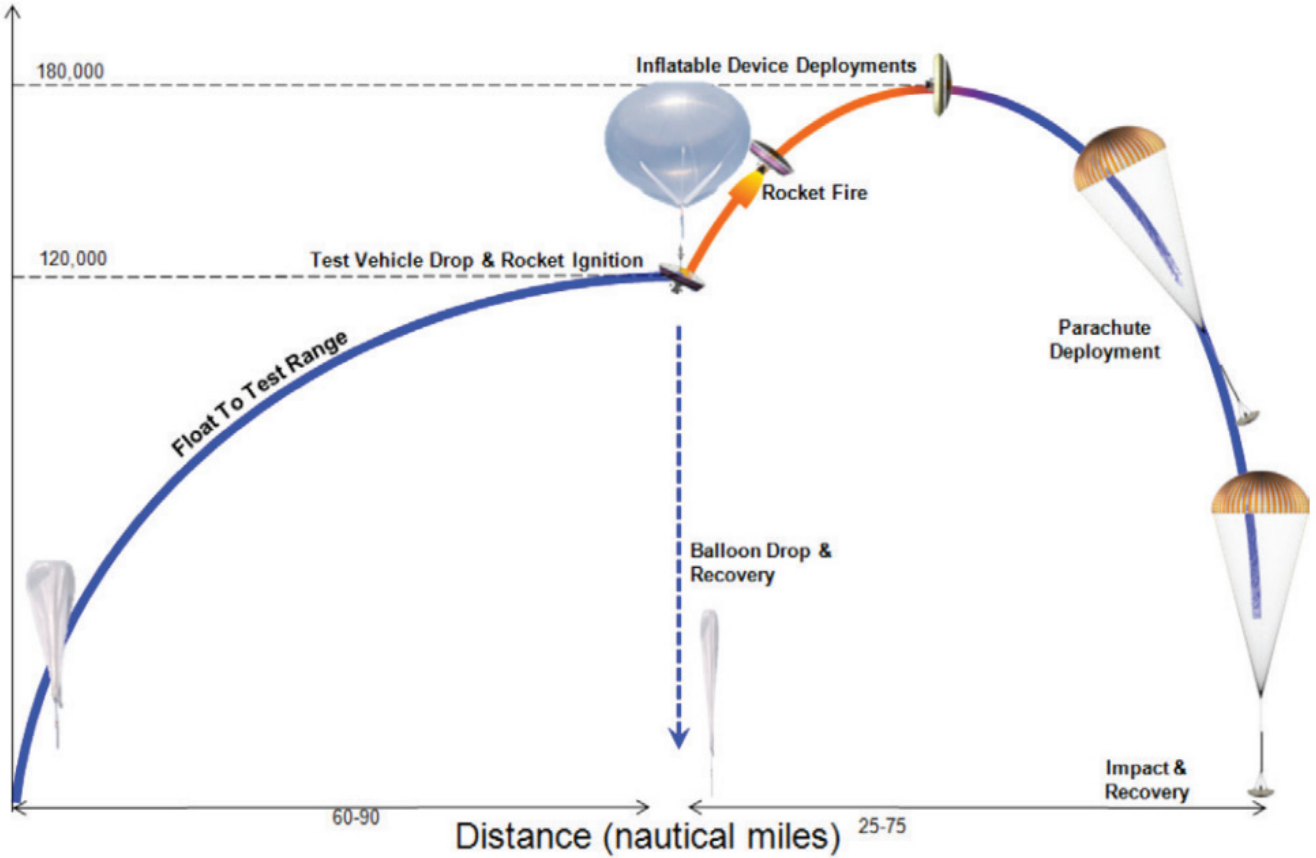


Image credits: NASA/JPL-Caltech

Image credit: NASA/JPL-Caltech

Lessons Learned / Implementation

- Modified project to allow mixing open/closed source code
- 32kB of SRAM adequate for ~5-6kB scripts with minimal table usage (~10kB used by Lua dynamic allocations)
- Extended eLua interrupts to provide event hooks
- Turnkey script with remote commands/settings or customized scripts
- Added watchdog to ensure VM is always running while awake

GSatMicro Code Structure

autorun.lua (simplified)

```
function satellite_signal ()
    -- handle satellite signal
end

function satellite_timeout ()
    -- handle no signal
end

function satellite_tx_ok ()
    -- handle successful transmit
end

function satellite_tx_fail ()
    -- handle failed transmit
end
```

```
function gps_valid ()
    -- handle valid gps
end

function gps_timeout ()
    -- handle no gps signal
end

cpu.set_int_handler( cpu.INT_SATELLITE_SIGNAL,
satellite_signal)
cpu.set_int_handler( cpu.INT_SATELLITE_TX_OK, satellite_tx_ok)
cpu.set_int_handler( cpu.INT_SATELLITE_TX_FAIL,
satellite_tx_fail)
cpu.set_int_handler( cpu.INT_SATELLITE_TIMEOUT,
iridium_timeout)
cpu.set_int_handler( cpu.INT_GPS_VALID, gps_valid)
cpu.set_int_handler( cpu.INT_GPS_TIMEOUT, gps_timeout)
```

Project Future

- Looking at Lua 5.3
  - Emergency garbage collection built-in (added in 5.2)
  - Bit manipulation built-in (added in 5.2), extended in 5.3
  - Supports 64-bit/32-bit int and float
- API updates to make event-driven programming easier

Questions?

- Project, Documentation, Resources:
  - http://www.eluaproject.net/
- Talk Materials
  - http://github.com/jsnyder/elua-escbos
- Contact

Bogdan Marinescu:	bogdanm@eluaproject.net
Dado Sutter:	dadosutter@eluaproject.net
James Snyder:	jsnyder@eluaproject.net

eLua Forks

- NodeMCU Firmware
  - Reworking and extension of APIs around event-driven model
  - Port to ESP8266
  - http://github.com/nodemcu/nodemcu-firmware
- Alcor6l
  - Adds Lisp & C support
  - http://github.com/simplemachines-italy/Alcor6L

eLua APIs

```
-- GPIO
WAV0_CS = pio.PC_0
-- pio.pin.setdir( direction, pin )
pio.pin.setdir( pio.OUTPUT, WAV0_CS )
-- pio.pin.sethigh( pin )
pio.pin.sethigh( WAV0_CS )
pio.pin.setlow( WAV0_CS )
val = pio.pin.read( WAV0_CS )

-- SPI
-- spi.setup( id, type, clock, cpol, cpha, databits )
spi.setup( 0, spi.MASTER, 1e6, 1, 0, 16 )
-- spi.write( id, data1, data2, data3 )
spi.write( 0, 0x23 )
status = spi.readwrite( 0, 0xFF )
```

eLua APIs

```
-- PWM
-- pwm.setup( id, frequency, duty )
pwm.setup( 0, 5000000, 50 )
-- pwm.start( id )
pwm.start( 0 )

-- ADC
-- adc.setclock( id, clock, timer_id )
-- adc.setclock( id, 0 ) -- no clock
adc.setclock( 0, 0 )
-- adc.setclock( id, length ) -- moving average filter
adc.setsmoothing( 0, 16 )
-- adc.sample( id, count )
adc.sample( 0, 1 )
-- adc.getsample( id, count )
sample = adc.getsample( 0 )
```

Documentation:
http://www.eluaproject.net/doc/master/en_refman_gen.html