Release Notes for CPAP Lite Software

Version 2.7.3

- This release is to be used with LCD units programmed with the new application "ProgramLCD" (see installer file here: https://drive.google.com/file/d/1YEunGWWDYTHI8v9Md0UD2ZdAWyiCoVI4/view?usp=sharing)

- Instead of hard-coding the image addresses in the firmware, the information is now all stored in the LCD FLASH along with the images.   This should eliminate the old step of copying image addresses from the LCD programming tool into the firmware. Note the order of the images during programming is very important: the index of each file is how the firmware figures out which address to use for the screen.

- During bootup, the table containing the screens and locations is printed on the terminal, e.g.

```
Entering Machine state SETUP_STATE
screen 1: flash: 0x2000, width: 800, height: 480
screen 2: flash: 0x1a000, width: 800, height: 480
screen 3: flash: 0x32000, width: 800, height: 480
screen 4: flash: 0x4a000, width: 800, height: 480
(etc.)
```

Version 2.7.2

- This release is NOT for the DEMO.

- NOTE: This release requires new screens, to be found here: https://drive.google.com/drive/folders/1P3KZXNMDZpomw7nefTuw3aeivfjIdmBB?usp=sharing

- New screens: "Occlusion Alarm" screen and "Low Battery" screen

- New button screens: "Lock", "Unlock", "Mute", "Muted", "Back", "Change", "Next", "Pause", "Run", and "Skip".

- Only show "Low Battery" screen when unplugged; when the CPAP is plugged in, never show "Low Battery" no matter how low the battery, since it's charging.

- Instead of using 4 screens for each state (with every combination of "Lock" and "Mute" buttons), use 1 base screen, and overwrite the proper button images. This reduces the number of full screens stored in LCD FLASH memory from 36 screens down to 21 screens.

Version 2.7.1

- This release is NOT for the DEMO. It is for our regular CPAP development stream, using a modified v4.5 board that accepts O2 sensor input.

- For the regular build we make the following modifications from the DEMO software

  - ◆ Enable Hi Pressure alarm

  - ◆ Enable Battery Alarm

  - ◆ Enable Occlusion Alarm

  - ◆ Enable Battery Monitor through Power Board (use opto-isolators for I2C protection)

  - ◆ For v4.5 board modifications:

    - ▪ O2 analog input on pin A7 (AIN7), O2 status input on pin B1 (AIN13), O2 calibrate pin on B0

    - ▪ Knob encoders changed from B0 and B1 to B5 and B6

  - ◆ Configure external interrupts for B5 and B6 to Interrupt 5 and Interrupt 6

  - ◆ Use 50-point averaging for O2 sensor and O2 status to smooth out readings

  - ◆ Set DC bias for prop valve control to "48" for Enfield valve. (We used "70" for SMC valve for demo.)

Version 2.6.8

- DEMO BUILD:

  - ◆ BUG FIX FOR LED FLASHES: The LED's were glitching brightly, briefly and intermittently. The fix is to load the PWM counter registers through a double-buffering technique (using "CCBUF"), instead of loading the counters directly (that caused a race condition). Verified this prevents the intermittent glitchy flashing. Leaving "pulsing" enabled now instead of flashing.

Version 2.6.7

- DEMO BUILD:

  - ◆ NEW SCREENS: The rebuilt screens are controlled with this firmware build. They include all lock and mute screens for setpoint, ramp and run screens. (Needed to adjust the position of the battery graphic and the firmware version printout.)

  - ◆ BUG ADDRESSED: Because the pulsing LED's cause glitches, just flash the LED's on and off. (Note this is a temporary solution.)

  - ◆ WATCHDOG: Now disabled for development and demos. (Now you have time to calibrate the touch screen after loading new screens.)

Version 2.6.6

- DEMO BUILD:

  - ◆ BUG FIX: Buzzer will sound as long as both unmuted and any alarm screen is present; buzzer won't silence until the alarm screen goes away

  - ◆ FEATURE CHANGE: Mute button now toggles mute condition. If mute is on, pressing mute button again disables mute.

  - ◆ FEATURE CHANGE: Instead of "pulsing" the LED's, the LED's will now flash on and off. (This is to avoid the glitchy "flash" that occasionally happens during pulsing.)

  - ◆ Disable watchdog for development and demo.

Version 2.6.5

- DEMO BUILD:

  - ◆ BUG FIX: Include "baby temperature" on the "ramping" screen (it was completely missing before)

  - ◆ DISPLAY IMPROVEMENT: Include degrees symbol "°" after "baby temperature" so it shows for instance "38°" instead of "38".

  - ◆ BUG FIX: When power on self test completes, the "SELF TEST COMPLETE" text no longer overwrites the "SELF TEST STARTING" text.

Version 2.6.4

- DEMO BUILD:

  - ◆ BUG FIX, KNOB ENCODERS: For the external IRQ peripheral, debouncer settings are frequency: Divided by 64 and Low Frequency Samples: 7. It looks like the encoder noise could be close to 1ms pulses, so setting the debouncer to about 2Khz. The glitching is almost gone now.

Version 2.6.3

- DEMO BUILD:

  - ◆ BUG FIX, KNOB ENCODERS: Add firmware debouncing to both knob inputs. For the external IRQ peripheral, debouncer settings are frequency: Divided by 4 and Low Frequency Samples: 7. Also, add 2usec delay after switching MUX to read encoder (MUX delay is about 500 nsecs).

  - ◆ For the tasks, instead of having them all multiples of 20msecs (so they all try to run at the same interval), make them odd mulitples, like instead of running the state machine at 100msecs, run it at 101 msecs.

◆ The units "%O2" were touching the numbers, e.g. with "24" the 4 touched the "%" sign, so moved it over a bit

Version 2.6.2

- DEMO BUILD:

  ◆ NEW FONT FILE: Changed address where font file is stored (for large numbers on run screens and alarm screens). Now able to display large numbers correctly.

  ◆ SWAPPING SCREENS: since there are different Alarm screens for muted, unmuted, locked, unlocked, the screens are now updated whenever the lock or alarm condition changes.

Version 2.6.1

- DEMO BUILD:

  ◆ NEW LCD SCREENS: This build requires new screens to run properly. The 27 new screens are from India, labeled Screen_1 through Screen_27, with about 6 screens still missing as of today.

  ◆ Link to the screens I'm using: https://drive.google.com/drive/folders/1UrHonXwzStTXon6qzlbrzp2qBs9QDQtI?usp=sharing.

Version 2.5.13

- DEMO BUILD:

  ◆ BUG FIX for Pressure overshooting: fix for Pressure control with demo unit plumbing: change parameters for Baby Pressure PID loop, KP is reduced from 10 to 1, and KI is reduced from 5 to 3. This gives decent pressure response with no overshoot.

  ◆ BUG FIX for POST failing. Make sure POST (Self Test) passes even if the thermocouples and circuit are all disconnected – the test only checks that the flow_insp increases when the blower is on, and the pressure raw readings are between 800 and 1500, and the heater and PCB temperatures are normal. Previously, this test assumed the circuit was connected to pass.

Version 2.5.12

- DEMO BUILD:

  ◆ Fix for FAILING Flow test during Power on Self Test: the flow sensors weren't being updated to track the blower in time, and the flow test was failing on startup. Also, flow_ox was sometimes returning a slightly negative number, which was failing. Flow test should always pass now

◆ Fix for alarm "beep" happening when adjusting the knobs quickly; the logic was letting a "Buzz" get through even before the 5 seconds had elapsed; now fixed.

Version 2.5.11

- DEMO BUILD:

  ◆ Fix for Knob Encoders jumping when spinning them too fast. The debounce filter in Atmel Studio IRQ configuration is now disabled. The problem was the "debouncing" circuit was filtering the signal SO much that the interrupt was delayed so much it was out of sync with the 2nd encoder output. This happened when spinning the knobs too fast.

Version 2.5.10

- DEMO BUILD:

  ◆ After 40 seconds in "RAMP" state ("Adjusting to New Setpoint") the alarms are enabled. So if the pressure or FiO2 setpoint is never reached during ramp-up, the alarms will start after 45 seconds.

  ◆ Fixes for resetting Flow Sensors (still not a reliable solution to I2C errors)

  ◆ Limit "Watchdog Feed" to once every 100msecs

  ◆ Increase resolution of LED pulsing – instead of using 0-100, use 0-10000 for smoother pulsing.

  ◆ KNOWN BUG: LED pulsing sometimes shows a brief "flash" – very intermittent

Version 2.5.9

- DEMO BUILD:

  ◆ Make regular LED brightness (yellow and green) dimmer (20% of maximum instead of 50%).

  ◆ Make alarm LED brightness still at 50%.

Version 2.5.8

- DEMO BUILD:

  ◆ Move "Back" button to lower left of screen, opposite "Forward" button; only on setup screens; icon for "Back" button is temporary pending new screens; old "Back" button is now masked off to be invisible

  ◆ Allow "Mute" even when screen is locked (other buttons and encoders still locked)

  ◆ Improve knob encoder response (more debouncing of Encoder signal); still a very-intermittent problem with slowly rotating the knob causing a value jump.

  ◆ (Remove large amounts of unused code in main.c)

Version 2.5.7

- DEMO BUILD:

  ◆ Improve knob encoder response (use only rising edge of encoder pulse for translation); still a very-intermittent problem with slowly rotating the knob causing a value jump.

  ◆ New "LOCK" button on the run screens to Lock the screen. When locked, the "LOCK" button will show "UNLOCK", and the other buttons and knobs will be ignored. Only the "UNLOCK" button can unlock the screen. Eventually, we will get an icon for instead of just the words "LOCK" or "UNLOCK".

  ◆ The "RE_CAL" button on the first run screen is now in button position "1", and button position "2" is reserved for the "LOCK" button.

Version 2.5.6

- DEMO BUILD:

  ◆ Disable "High Pressure" alarm for DEMO unit (compiled out)

  ◆ Ability to abort "Power on Self Test" by clicking "next"

Version 2.5.5

- DEMO BUILD:

  ◆ Mute button is active for each screen, pushing will mute all buzzes for 30 seconds.

  ◆ Mute button disappears from screen when "mute" is active; reappears in 30 seconds

  ◆ During Splash and POST, LED's will be "bright blue"

  ◆ FiO2 actual display will be rounded to 1% (instead of rounding to 5%); update rate for numbers is 2 times per second

Version 2.5.4

- DEMO BUILD:

  ◆ For Ramping and for Alarm states, the LED's will "pulse", meaning ramp up and down in a sinusoidal fashion, instead of blinking.

  ◆ FiO2 prop valve tuning:

    ▪ Reduce the propvalve ramp_rate from 0.5 to 0.2 to get better control

    ▪ Start the loop at prop valve "70" instead of "0" to get to the setpoint sooner.

Version 2.5.3

- DEMO BUILD:

  - Mute button silences alarm for 30 seconds (instead of forever), then alarm comes back on.

  - Knobs can now be set with "pressSetpt()" and "fio2Setpt()", so they can be started at a known value instead of "minimum". Default on settings are 5cmH2O and 21%O2.

  - Low pressure alarm is 2.0cmH2O below setpoint for 5 seconds. Cancel low pressure alarm when above 1.5cmH2O below setpoint for 5 seconds.

  - Low FiO2 alarm is 10% below setpoint for 10 seconds.

  - Cancel low FiO2 alarm when above 7% below setpoint for 5 seconds.

Version 2.5.2

- DEMO BUILD: Includes

  - No O2 sensor capability or checking

  - Encoder knobs working using PB00 and PB01

  - LED Color styles implemented, including blue on setup, pulsing green on ramping, solid green on steady state running, red flashing on alarms, and yellow on pause

  - Occlusion alarm disabled

  - Mute button implemented (currently mutes permanently for each alarm)

  - Heat plate now servoing on "35 degrees" for demo safety (not 74 degrees)

  - On Power Up Self test, which is now enabled on every power up, use battery voltage instead of O2 report – Self Test always passes

Version 2.4.14

- BATTERY MONITOR DISABLED: disable the I2C to the Power board to monitor battery level and AC plugged in because of the I2C errors. The battery level and AC power status are now invalid

- I2C ERROR MONITORING: add printouts if there is I2C bus contention

Version 2.4.13

- ENCODER KNOBS: now working. Can be enabled with "toggleKnobControl" and they will become live and control FiO2 and Baby Pressure.

◆ Must enable Interrupt 5 settings and Interrupt 6 settings in Atmel Start (for EXTERNAL INTERRUPTS) since new pinouts has PB05 using interrupt 5 and PB06 using interrupt 6. (Had to re-generate project in Atmel Start).

◆ Make sure FiO2 knob goes in even 5% increments (e.g. 21, 25, 30, 35, ..., instead of 21, 26, 31, 36, etc...)

◆ Be sure the mux switch common SW_COMMON_PIN is PB23, not PB07 (lingering mistake from using O2 Modbus control and changed SW_COMMON to PB07 for that)

Version 2.4.12

- LCD SCREENS: Now display software version on display after power up.
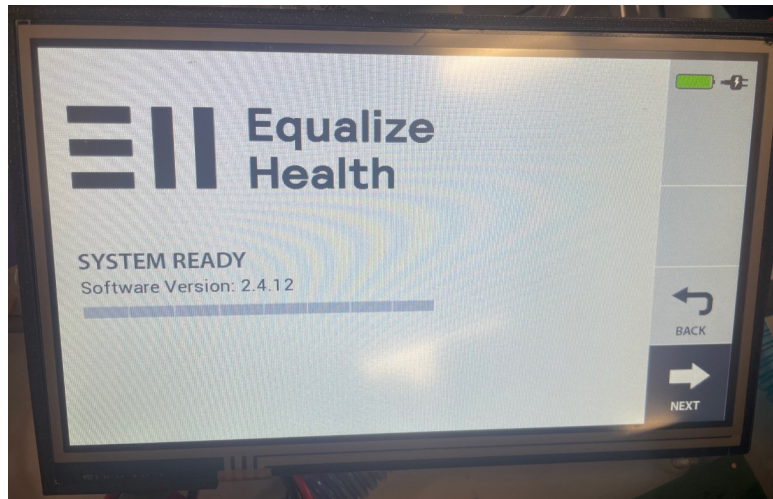
- KNOBS: Fix encoder pin assignment. (Was PB00 and PB01, should be PB05 and PB06)

- FIO2 ALARM: disable for 8 seconds after changing FiO2 setpoint

- Change initial FiO2 ramp rate from 1.0 to 2.0 to speed up initial ramp up.

- FIO2 LOOP: disable loop if flow sensors are giving bad readings (e.g. when I2C errors are happening)

Version 2.4.11

- POWER ON SELFTEST: Not compiled in yet. This self test will execute after every power up or reset, and the self test results will display on the LCD screen when this is eventually compiled in. It runs the blower at "blower(250)" and checks the 2 flow sensors, the 2 pressure sensors, the oxygen sensor, and the temperature sensors of the heat plate, and the temp_insp and temp_exp.
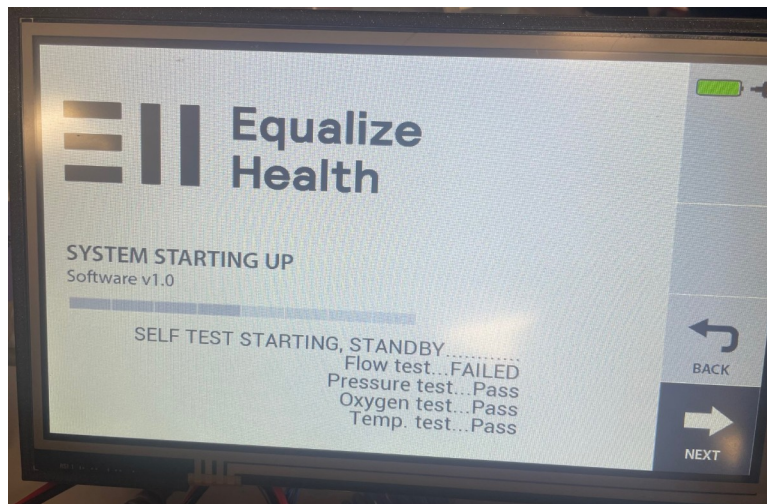
- FIO2 FILTERING: To make the screen display more reasonable, a new heavily-filtered version of the FiO2 reading is used. This filtered version is also used for alarms.

- FIO2 CALIBRATING: With the faster prop valve controls, the delay before starting the O2 calibration is increased from 10 seconds to 15 seconds to let the O2 sensor catch up.

- STACK OVERFLOW: A stack overflow was seen on the State Machine task on one of the test platforms, so the stack for the State Machine task is increased by 2x.

Version 2.4.10

- FIO2 CONTROL: New ramping function for FiO2 from Costa. Controls are "pvramp()" to set the number of counts per increment of ramp and "fio2tol()" to set the FiO2 tolerance band. Current defaults are "pvramp(0.5)" and "fio2tol(0.5)".

- OCCLUSION ALARM INHIBIT: Per Robin, the occlusion alarm will be inhibited when the blower control has increased > 10 counts in the last 10 seconds. Once the blower is no longer increasing, the occlusion alarm will be active. This is necessary in the example where a hose is completely disconnected and the blower ramps up a lot, then reconnected and the blower comes back down. Without this inhibit, the occlusion alarm gives false alarms.

- MULTIPLE ALARMS: Since many of the alarms, e.g. FiO2 and occlusion or FiO2 and Low Pressure occur at the same time, we should handle simultaneous alarms.

- LCD SCREENS: Add button "RE-CAL" to basic run screen (button 2 position), so user can re-run the circuit calibration. This is only accessible from the initial "Run" screen where all systems are off. Also, numbers on alarm screens (e.g. baby pressure and FiO2) are now active and updating.

Version 2.4.9

- LCD SCREENS: Make all fields active on alarm screens, including FiO2 and Baby Pressure actual and setpoints, temperature and battery icon

- LCD SCREENS: LCD screens are now active on this build; if the LCD is missing, the code will flag that and continue, if the LCD is present it will be active and usable

- I2C ERRORS: Instead of flooding the screen, the I2C errors will display intermittently, so the terminal screen doesn't flood

- CONFIG FILES FOR MPLAB IDE: config files needed to use MPLAB IDE tool, and to use J-Link debugger

Version 2.4.8

- I2C ERRORS: Remove the board reset function after getting 100 I2C errors. Now the board will never reset, no matter how many errors occur on the I2C bus.

- LCD SCREENS: The "Power Connected" icon is now active: if AC power is connected, the icon will display, if AC power is removed, the "Power Connected" icon will disappear, and only the battery indication will display.

Version 2.4.7

- BATTERY MONITOR: Set limits for battery voltage:

  - Below 23.0 volts, declare an "attention" area (color code Yellow)

  - Below 21.0 volts, declare a "battery warning" area (color code Red)

  - These colors and codes will show up when using LCD display

- LCD DISPLAY: Fix baby pressure and FiO2 displays to look clean

- LCD DISPLAY: Show baby temperature in real time on screen

- NOTE: LCD display is disabled by default, until everyone has a v4.5 board or above

Version 2.4.6

- HEATER CONTROLS: Heat plate temperature limit changed from 79 to 74, per Robin and Costa. The firmware shouldn't let the heat plate above 74, there will be a mechanical shutoff somewhere around 80.

Version 2.4.5

- HEATER CONTROLS: Implementation of Robin's heater requirements:

  - Heat wire should servo on t_prox, setting at 39 degrees

  - Heat Plate should servo on t_dist, setting at 37 degrees

- Heat plate shouldn't exceed 79 degrees, so while ramping up the heat plate, we will actually servo on the heat plate thermistor at "79 degrees", and when we're within 2 degrees of 37 on t_dist, we'll switch over and servo on t_dist at 37 degrees.

- Change "ki" for heat wire from "0" to "1". We were never actually reaching 39 because the integration term was 0.

- Remove printouts of "Prev_flow: .. prev_p_exp:" used for Occlusion alarm debugging

- Fixes for FLASH behavior: make sure we release the semaphore before doing "flash_wait_busy()", because it needs semphore, too. Also, use semaphore in "flash_erase_sector()", since it was missing.

Version 2.4.4

- OCCLUSION ALARM: Implementation of Tanner's occlusion conditions:

```
The occlusion alarm should sound while both of the following are true:
     1. The average inspiratory flow decreases by a minimum of 1 LPM over the course
     of 3 seconds and remains there for at least 5 seconds
     2. The % difference between the inspiratory and expiratory pressure decreases by
     a minimum of 10% over the course of 3 seconds and remains there for at least 5
     seconds.
```

- NOTES: When the alarm is met, the message appears "Got Occlusion Indication wait 1 seconds" and the red LED's will flash if connected. There is a 5 second delay to "kill" the occlusion alarm, when this happens the message appears "Alarm ending delay complete". There are numerous debug statements on the terminal meant to help debugging the occlusion alarm which will be removed later. If there is a problem, recording all the debug statements will help in trouble-shooting.

Version 2.4.3

- FiO2 CALIBRATION (to O2 sensor) CHANGES:

  ◆ Allow any calibration factor from 21 to 100 (before, I was limiting it to 80-120%).

  ◆ Redo the FiO2 calibration whenever the user changes the FiO2 setpoint. Wait 10 seconds after the FiO2 setpoint is reached by the PID loop, then run the FiO2 calibration with the O2 sensor. The O2 sensor takes > 5 seconds to catch up to the FiO2 readings

  ◆ Requirements to do FiO2 calibration:

    1.1 FiO2 actual is within 0.4 of FiO2 setpoint

    1.2 10 seconds elapsed since last FiO2 setpoint change

    1.3 Blower > 200

    1.4 O2 sensor reading > 20.0 (when warming up, the O2 sensor reads typically 1 or 2)

    1.5 flow_ox > 0.35

◆ When the O2 calibration factor is found, limit all further FiO2 settings to that factor. For example, if the calibration factor is 80, then don't allow any FiO2 setting above 80.

- I2C ERRORS: Only keep track of I2C errors from the Flow sensor board. I2C errors from the Flow sensors will generate a board reset when they total 100. But I2C errors from the battery monitor or from the power monitor or from the blower will NOT generate errors, no matter how many.

- FIO2 PID LOOP: Use a bias of 4100 for the prop valve instead of 3000. At low O2 tank pressure, the prop valve has no effect below about 4500 setting.

Version 2.4.2

- NEW FEATURE: Set the PID maximum for each of the 4 PID loops using "kmax(x,value)". For instance, to set the heat_plate maximum to 10000 for the PID loop, use "kmax(2,10000)", where: `x=0:fio2,x=1:press,x=2:heat_plate,x=3:heat_wire.` If you do a "saveAll" after entering the maximum, the value you entered is saved to FLASH.

- BUG FIX: the blower limit is now held for 5 seconds after the flow condition that caused the limit is removed. Also the blower "integral" term is limited, so when the condition is active, the integral does NOT increase. Both of these together should ensure that the blower should not increase beyond whatever the blower setting is at when the flow condition is sensed.

- BATTERY MONITOR ON POWER BOARD: is now enabled on the I2C bus. If the cable to the Power board (connecting to P12 on the main board) is missing, this will generate a stream of I2C errors.

Version 2.4.1

- NEW FEATURE: Watchdog implemented. If code hangs up for more than 4 seconds, the "watchdog" should bite and reset the processor. The watchdog is fed in the "Idle Task", which only runs when all the other tasks are not running. (Terminal command "triggerWatchdog" will put the code into an unrecoverable loop, and the watchdog should bite and reset the board after about 4 seconds.)

- NEW FEATURE: Battery backup of RTC. The time should survive power cycles after the watch battery is in place and the "BOD" fuses on the MCU are set. (In the Microship Studio project, go to "Device Programming", click "Apply", select "Fuses" and change "BOD33_DIS" to unselected, and change "BOD33_ACTION" to "The BOD33 puts the device in backup sleep mode". Then click "Program" and the battery backup should work.)

- BUG FIX: the blower speed wasn't updating normally, so remove the "return early" code.

Version 2.3.13

- BUG FIX: Zero pressure sensors works now. There was a conflict between different measurements of the ADC, so there were intermittent bad readings causing the problem

(reading other ADC channels when trying to read pressure). Need to put the "semaphoreTake()" BEFORE the set_adc(channel) selection, not after.

- Remove "Baby Pressure Offset", which was the offset (usually about -0.3) that Baby Pressure showed with the blower off. Now, this will not be used, and the Baby Pressure value will be straight from the equations.

- O2 SENSOR: O2 calibration will not be allowed until the O2 Sensor has been on with status "good" for 10 minutes. The 10 minute timer starts with the O2 sensor status is OK (status 1) and the O2 reading is greater than 5 (for the first 1-2 minutes, the O2 reading is usually 1 or 2).

- BUG FIX: getting "Timer Task" Stack overflow errors, increase stack size from 64 to 100.

- TIMING: reduce the "sample_adc(50)" to "sample_adc(20)". I don't believe that a large sampling of the ADC is needed.

- I2C ERROR IMPROVEMENTS: when reading the Flow sensors over I2C, do a "ENTER_CRITICAL()" function to prevent task swapping or RTOS interference. Increase delays in "flow_reset_sensor" to put 200msecs after releasing the RESET line for the Flow sensor power.

- CALIBRATE BUG: when "calibrate" starts, disable the FiO2 and Baby Pressure PID loops. Previously, if calibrate was attempted while under PID control, the PID loop would try to keep taking over from the calibration task.

Version 2.3.12

- DEBUG PROP VALVE: Set DAC0 (pin PA02) for every update to the Prop Valve. PWM is still running (pin PA12), so select desired control signal using jumper on JP1. DAC0 is selected by jumping pins JP1-1. PWM is selected by jumping JP1-2. (See silkscreen on back of board.)

- BUG FIX: In the Flow Sensor reset logic, hold reset for 160msecs instead of 80, and after resetting, delay 250 msecs before resuming I2C operations.

- I2C ERROR RESET: If >100 I2C errors are recorded, then consider that the flow sensors are unrecoverable and do a soft MCU reset.

- DEBUG FREERTOS: Collect RTOS task statistics, display with new command "runTimeStats". New timer "TIMER_1" runs at 20Khz to collect task statistics.

Version 2.3.11

- BUG FIX: FiO2 will calibrate to the O2 sensor if the flow_ox is > 0.3. It was previously set to calibrate only if flow_ox > 2.0, which meant at low FiO2 settings it never calibrated.

- FiO2 CONTROL LOOP: change bias of PID loop to be FIO2_MIN of 0 (instead of 50), FIO2_MAX is 75 (instead of 95) and FIO2_BIAS is 30 (instead of 63). (FIO2_BIAS is where the control loop starts hunting)

Version 2.3.10

- FEATURE CHANGE: FiO2 will now calibrate to the O2 sensor if the O2 sensor reading is > 25 (changed from > 60).

- BUG FIX: programming ".bat" file now working again

Version 2.3.9

- FEATURE CHANGE: The battery monitor on the Power board is disabled in firmware. To remove electrically from the circuit, disconnect cable from P12 (disconnects I2C). Should improve I2C error problem.

- FEATURE CHANGE: New equations for press_baby, press_ckt_exp, press_ckt_insp and press_ckt.value, calculate c_leak and c_insp in "calibration" when c_factor is calculated.

```
press_baby.value = press_ckt.value - (c_leak * flow_leak.value * flow_leak.value);

flow_leak.value = flow_insp.avg - flow_exp.avg;
float press_ckt_exp = press_exp.avg + (0.00218 * flow_exp.avg * flow_exp.avg) + (0.0623
* flow_exp.avg) - 0.0817;
float press_ckt_insp = press_insp.avg - (c_insp * flow_leak.value * flow_leak.value);
press_ckt.value = (press_ckt_exp + press_ckt_insp) / 2.0;

MUST BE DONE AS PART OF "CALIBRATION" TO CALCULATE c_leak AND c_insp
calx->press_ckt_exp = calx->press_exp = (0.00218 * flow_exp.avg * flow_exp.avg);
calx->c_leak = calx->press_ckt_exp / (calx->flow_leak * calx->flow_leak);
calx->c_insp = (calx->press_insp - calx->press_ckt_exp) / (calx->flow_insp * calx-
>flow_insp);
```

- In "configASSERT()" print out error message.

- Increase FreeRTOS heap size form 19200 to 24000

- Create binary semaphore for ADC. Prevents different consumers of ADC (on different threads) from interfering with channel selection of the ADC.

- FILTERING CHANGE: Increase standard Flow averaging to 10 (instead of 5); increase standard Pressure averaging to 10 (instead of 6).

Version 2.3.8

- FEATURE CHANGE: O2 analog sensor enabled (use command "o2Status" to read out values)

- O2 CALIBRATION IMPROVEMENT: To toggle the "O2 Calibration" output, which must be high for 1 second, change the code to increase the width of the pulse:

```
gpio_set_pin_level(O2_CALIBRATE_PIN, true);
os_delay(2100);  // was os_delay(1100)
gpio_set_pin_level(O2_CALIBRATE_PIN, false);
```

- O2 CALIBRATION PROTECTION: When calibrating the FiO2 to the O2 sensor every 10 minutes, put restrictions on to prevent bad calibration:

- flox_ox > 2.0
- O2 reading > 60
- blower speed > 2000
- FiO2 within 2% of setpoint in PID loop
- Resulting calibration must keep factor in range 80 < o2_factor < 120.

Version 2.3.7

- BUG IMPROVEMENT: Only do averaging of 6 samples for p_insp and p_exp for regular measurements and PID loops, but during c_factor calibration and zeroing pressure sensors do 30-sample averaging for smoother, more accurate results.

- BUG IMPROVEMENT: For I2C errors,When reading I2C for flow, if the result is an error, try waiting 400usec and turn on the flow sensor measurements again (command 0x1000 to the SFM3400)

Version 2.3.6

- BUG IMPROVEMENT: For I2C errors, Put 2usec delay in reading flow sensors (I2C address 0x40).

- Add Flow Sensor soft reset in "init_flow" for resetting I2C errors.

- Add blower control limits during press_baby PID loop: If p_limit > setpt+10 (per Robin's equation), try to limit blower speed (not tested).

- Put PID "max" value into "pidDump" for debugging blower speed limits

- New "delay_usec(n)" function in utils_user.c.

Version 2.3.5

- BUG FIX: Working LCD screens and touch buttons with Rev. 4.5 main board. SPI bus working with LCD and with external FLASH, nor FLASH corruption problems detected. New SPI bus semaphore so different RTOS tasks can share the SPI bus peacefully. Big and small numbers now updating on screens. NOTE: LCD screens DISABLED in current software to be backwards compatible with old boards.

- BUG PROGRESS: Getting I2C bus errors (scrolling off screen on terminal). Fix for now is the reset flow sensor board and reset I2C bus on main processor, whenever more than 8 I2C errors are detected. Increase I2C Bus semaphore timeout from 40 to 209.

- IMPROVEMENT: Remove FiO2 averaging (per CG). Change pressure PID coefficients to: P=10, I=5, D=0. Change FiO2 coefficients to: P=1.0, I=1.0, D=1.0 for new Enfield

proportional valve. Change flow averaging from 50 samples to 5. Change pressure averaging from 50 samples to 3. Change FiO2 averaging from 50 samples to 5. (per CG)

- BUG FIX: Encoding knobs now working. To make them "active" for the setpoints, you must execute the "toggleKnobControl" command, then the knobs directly control pressure and FiO2. In code, "Knob1" is replaced with "Knob_fio2", "Knob2" is replaced with "Knob_press".

- BUG FIX: Serial number for boards should now be stored and retrieved correctly

Version 2.3.4

- BUG FIX: in c_factor calculation, make flow_leak = flow_insp-flow_exp. In all previous firmware versions the bad equation was:

  - `calx->flow_leak = get_flow_insp() - get_flow_ox();`
    - Corrected equation:
      - `calx->flow_leak = get_flow_insp() - get_flow_exp();`

  (NOTE: this bug fix is only for the c_factor calculation during calibration; "flow_leak" was calculated correctly in the regular program flow.)

Version 2.3.3

- NEW FEATURE: New operating system "FreeRTOS" implemented. Tasks all running on separate threads, scheduled by RTOS so each runs for an equal part of the time, unless it is suspended. All tasks on equal priority except "Alarm" thread at higher priority. No statistics implemented yet.

- NEW FEATURE: Alarms now implemented:

  Implement 4 alarms:
  1) low pressure (press_baby < setpt – 1.5)
  2) high pressure (press_baby > setpt + 1.5 OR
             press_baby > 20   OR
             p_insp almost equal p_exp)
  3) low FiO2 (fio2 < setpt - 7)
  4) low battery (vBatt < 20)

  All alarms have a 5 second delay before firing. All alarms have a 3 second delay before cancelling.
  All pressure alarms are only active during "Run" state when the pressure is servoing under PID control loops, not during setup or ramping (alarms are disabled during setup and ramping, except battery alarm is always active)

- BUG FIX: Battery voltage now sent up to Host App

Version 2.2.11

- NEW FEATURE: Battery monitor on Power board is now communicating with the main CPU. Using the "battery" command we can now display current, voltage, temperature and charge: `Batt. voltage: 25.13V, current: 0.23ma, charge: 95.9%, Temp: 27.3degC` Battery registers are being read once per second, then converted to floating point numbers as needed.

- BUG FIX: When hitting the "Exit" button on the "Low Battery" alarm screen, return to the "Run" screen.

Version 2.2.10

- BUG FIX: When entering kp, kd, and ki parameters (e.g. kp(1,3.4) for baby pressure PID proportional value), the values are setup for FLASH storage. If the command "saveAll" is sent before rebooting, the values are stored in FLASH. The values entered in kp(), kd() and ki() will be used even after reboots or power cycles, as long as the "saveAll" command was entered.

Version 2.2.9

- NEW FEATURE: By enabling the Oxygen Sensor (setting O2_SENSOR to "1" in main.h) the Modbus O2 sensor interface is enabled over the USART_0 port, using pins PA22 and PA23. The O2_SENSOR = 0 by default, so the O2 sensor is normally disabled and the Modbus is not configured by default.

- NEW FEATURE: When the oxygen sensor is enabled, the FlowWorks Hostapp will display O2 readings on the Pneumatic screen (requires v1.1.10 or above).

Version 2.2.8

- BUG FIX: FiO2 calculation is unstable at low flows (low blower settings), so don't calculate FiO2 until blower above 100.

- FEATURE: state machine cycles through available Alarm screens (using "Next Alarm" button) and coordinates with FlowWorks on Windows.

- FEATURE: add yellow, green and red LED's to states "ramping up", "running" and "alarms".

Version 2.2.7

- BUG FIX: Make FiO2 Control loop more responsive by changing PID parameters (using 50PSI pressure)

- When Calibration finishes, move state to "RUN" state so user doesn't have to push "Next"

- INTERLOCK: Only allow FiO2 loop (Prop valve to open) when blower has started moving

- When FiO2, Baby Pressure are within limits (5% and 0.35cmH2O), move from "ADJUSTING TO NEW SETPOINT" screen to "Running" screen.

Version 2.2.6

- BUG FIX: fix assignments of Pressure and FiO2 setpoints; use 3.0 and 21.0 as default (if nothing in FLASH), don't read setpoints from knobs unless knob selection is enabled.

- NEW BEHAVIOR: flow of states between "ready to run" to "ramping" to "running" now smooth; "Pause" button now shuts down system

- NEW BEHAVIOR: the "Self Test" screen will now start a "c_factor_calibration". The old behavior was to start a "power_on_self_test", which was wrong.

Version 2.2.5

- BUG FIX: when using the HeatPlate PID loop with maximum value of 10000, the standard board smokes. Reduce the PID maximum value to 2000 to prevent board damage.

- ENHANCMENT: handle states of "running" and "pause" in the state machine

Version 2.2.4

- NEW BEHAVIOR: The output stream from "avgStream", will now include 5 extra parameters at the end: HeatWireSetpt, HeatWireActual, HeatWireControl, HeatWireError, HeatWireIntegral. (NOTE: this may be removed in an upcoming release)

- NEW BEHAVIOR: The 2 output streams "avgStream" and "pidStream" can now work together or separately. If both are requested, they will alternate (avgStream,pidStream,avgStream, etc.). The output rate can still be set with "avgStreamRate(hz)".

- FIX: the "Self Test" feature will no longer be "blocking". It will be run as a state machine, reentrant, updated every 20msecs, allowing all other normal functions to run at the same time.

Version 2.2.3

- NEW FEATURE: Create state machine and LCD screen drivers, move through screens with button control.

- HOST SUPPORT: Host can change screen by sending button changes, e.g. "button(4)" for "Next", and Host can read back screen status to know which screen to display.

- BUG FIX: In the "avgStream" make sure that FiO2 is always less than or equal to "100".

Version 2.2.2

- NEW FEATURE: Support Windows Host App (called "FlowWorks") by uploading data and status on demand to support extensive GUI interface showing sensors and controls.

- NOTE: FlowWorks on the laptop won't work with any firmware version less than 2.2.1.

Version 2.2.1

- BUG FIX: heat wire PWM now working. Now all 6 PWM controls work together.

- Convert "calibration" and "wait for blower to stop" routines to all "re-entrant" code, so nothing stalls (hogs CPU) waiting for completion
- NEW FEATURE: sendStatus and sendData commands coming from Host App "FlowWorks" now supported

Version 2.1.20

- FEATURE CHANGE: Max plate heater control value in the heat plate PID is increased from 5000 to 10000 to get the full 6A of current running to the heater plate when under PID control.
- FEATURE CHANGE: Now support knobs using encoder instead of potentiometer. Signals KNOB1 and KNOB2 will now generate interrupts (`irq_FIO2_PB00_encoder` and `irq_PRESS_PB01_encoder`), and SW1 and SW2 are connected to the other 2 encoder signals, which are combined to sense "CW" and "CCW" rotation pulses.
- FEATURE: The "power" command now will include the battery voltage of the on-board watch battery (read through the ADC)
- KNOWN LIMITATION: The "heat wire" PWM control is not working, so it is disconnected. The heat wire will NOT work in this release.

Version 2.1.19

- FEATURE CHANGE: Instead of printing out the column headers in "avgStream" every 15 lines, only print them once on startup, and never again. Put a comma at the start of every line printed in avgStream to make Excel imports cleaner.
- Example Log from TeraTerm with timestamps and commas (no headers):

```
[2021-04-01 21:36:28.216] ,000.53,000.14,01.83,00.00,20.76,19.91,20.34,27.50,021.07,000.38,000.65,001.18
[2021-04-01 21:36:28.415] ,000.53,000.14,01.83,00.00,20.77,19.90,20.34,27.50,021.07,000.38,000.65,001.18
[2021-04-01 21:36:28.614] ,000.53,000.14,01.83,00.00,20.77,19.90,20.34,27.50,021.07,000.38,000.65,001.18
[2021-04-01 21:36:28.813] ,000.53,000.14,01.83,00.00,20.77,19.90,20.34,27.50,021.08,000.38,000.66,001.17
[2021-04-01 21:36:29.016] ,000.53,000.14,01.82,00.00,20.77,19.91,20.34,27.49,021.08,000.38,000.65,001.17
[2021-04-01 21:36:29.216] ,000.53,000.14,01.82,00.00,20.77,19.91,20.34,27.49,021.08,000.39,000.66,001.17
[2021-04-01 21:36:29.416] ,000.54,000.14,01.82,00.00,20.77,19.91,20.34,27.49,021.08,000.39,000.66,001.17
[2021-04-01 21:36:29.616] ,000.54,000.15,01.83,00.00,20.77,19.91,20.34,27.49,021.09,000.39,000.66,001.16
[2021-04-01 21:36:29.816] ,000.54,000.15,01.83,00.00,20.76,19.91,20.34,27.49,021.10,000.39,000.66,001.16
```

Version 2.1.18

- BUG FIX: Make the interval in printouts in "avgStream" more precise. There was a bug where a 5Hz output rate ("avgStreamRate(5)", the default) was resulting in 220msecs period instead of 200 msecs period. This is fixed, and should give more accurate intervals for all settings of avgStreamRate(x).

Version 2.1.17

- IMPROVEMENT: Change the blower open loop startup accel from .22 to 57 to reduce startup lag. Change the closed loop accel from .04 to .77 to speed up blower speed changes. This

decreases the blower lag on startup from 7 seconds to 2 seconds, and speeds up the movement between blower speeds.

- INTERLOCK IMPROVEMENT: Add a feature to limit the blower output depending on the pressure setpoint. By measuring typical blower vs. baby pressure values, I created a zone of possible blower settings, and limit the output of the pressure PID loop to these values to prevent blower run-away when the circuit is opened.

- BUG FIX: the zero_press_baby calculation is fixed to work now

- INTERLOCK: if the temperature sensors are disconnected, the heater PID loops are disabled for both the heat plate and heat wire

- INTERLOCK: if the blower isn't running, the heat wire PID loop is disabled (need air moving through the tube to reach the temperature probe near the baby, or the heat wire could run away)

- FEATURE: the up-arrow will now go through the last 10 commands (the down-arrow moves the opposite way in the buffer)

Version 2.1.16

- BUG FIX: if the temperature probe is removed, or the circuit is completely removed from the humidifier, while the baby pressure is being controlled by the PID loop, we will now just hold the blower at whatever value it was at until normal pressures are restored, then continue the PID loop. We use the baby pressure < -1.0 as the indicator that the pressure is not valid to indicate we should NOT run the PID loop for baby pressure, just leave the blower at whatever value it was at.

- BUG FIX: as a backup to the previous fix, the PID integral term for baby pressure will be limited to 511. There were situations (like opening the circuit) where the integral term would keep increasing out of control, which means the PID loop took minutes to respond while the blower was at maximum and the integral term was greater than 3,000.

Version 2.1.15

- BUG FIX: wait for blower speed to drop to 0 before continuing. Avoids problem of trying to zero pressure sensors before blower has a chance to drop to 0.

- LED strip color fully adjustable. Using command "leds(x,y,z)" the three colors R, G, B, can be adjusted, with the range in percent, 0-100. For instance bright white is "leds(100,100,100)", dim yellow is "leds(10,10,0)", medium blue is "leds(0,0,50)". The 3 LED controls are now controlled by PWM signals.

Version 2.1.12

- Add "F_LEAK" to avgStream printout (at the end)

- Add "zeroBabyPress" command so if the baby pressure at "no pressure" is -0.3, this command will figure out the offset and use that to make the calculation of baby pressure more accurate

- (Move the state machine from "main.c" to new module "states.c")

- (Fix bug in "calibratePress" routine.)

Version 2.1.9

- New repo using AtmelStart tool: EqualizeHealth_CPAP

- RTC and date and time implemented (using internal 32kHz oscillator)

- Power monitoring:

  - Bus: 24.15V, shunt: 3.711mV, current mA: 74.22mA, power: 275.42mW

- Command "calibrateFiO2" figures out the bias in the Prop Valve control for a given O2 tank pressure, typically around 73% at 50PSI.

- Tuning of FiO2 PID loop for less overshoot

Version 2.1.4

- New terminal interface

- Features:

  - Help screen, type "?" or "help"

  - Input ignores case (capitalizations don't matter)

  - Arguments for commands are given within parentheses, e.g. "PressSetpt(2.5)" will interpret the argument as value 2.5 for the baby pressure setpoint.

  - "Backspace" and "up-arrow" supported, allows backing up to delete inputs, and up-arrow will return last command

  - Help screen shows firmware version (e.g. Version: 2.1.4) and Board Serial Number (e.g. B100104)

  - "rawStream" will output raw sensor readings at 50mS interval (e.g. 958 for pressure); inputting "rawStream" a 2nd time toggles the output off

  - Typing anything will momentarily halt the stream

  - "avgStream" will output converted sensor readings at 200mS interval (e.g. 1.57 for pressure)

  - All output devices can be driven directly:

- blower(200) – runs the blower (open-loop) at 200 out of maximum 511

- propValve(50) – opens the O2 proportional valve at 50%

- heatPlate(5000) – turns on the heater for the humidity chamber at 5000 out of 10000

- heatWire(6000) – turns on the heater for the wire in the circuit at 6000 out of 10000

○ For PID control, first set the setpoint for the 4 parameters:

- FiO2Setpt(50) – sets the desired FiO2 reading to 50% oxygen (range 20 – 100)

- heatPlateSetpt(50) – sets the desired heat plate temperature to 50 degrees C.

- heatWireSetpt(30) – sets the desired circuit temperature to 30 degrees C.

- PressSetpt(2.8) – sets the desired baby pressure to 2.8 cmH2O

○ To engage active PID control:

- toggle PIDHeatPlate – will actively servo on the heatPlateSetpt

- togglePIDHeatWire – will actively servo on the heatWireSetpt

- togglePIDFiO2 – will actively servo on the FiO2Setpt using the proportional valve

- togglePIDPress – will actively servo on the Baby Pressure using the blower

○ "pidStream" will output the control and setpoint values for all the PID loops

○ "pidDump" will output the PID loop values once, plus the PID constants: kp, ki, and kd.

○ "showFlash" will show all the values that are primed to be stored in FLASH, or have been loaded from FLASH at startup

○ "saveAll" will save the parameters in FLASH, e.g. c_factor, pressure offsets (from zeroSensors), and setpoints

○ "SerialNumber(B100104)" will set the board serial number to the argument (e.g. B100104) and will be permanently stored in FLASH after the command "saveAll".

○ Reboot – will allow the board to be reset from the terminal (e.g. to abort all PID functions)

○ "calibrate" – runs the "zeroSensor" command to calculate the pressure sensor offsets at no pressure, then runs the blower at several different speeds and calculates c_factor for the given disposable rig. These calibrated values will be permanently stored in FLASH with the "saveAll" command

○