Low cost, low power data acquisition hardware

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1 Abstract

The Indoor air quality in New Zealand housing and buildings is an important area of research for Building Research Association of New Zealand (BRANZ), and tools which can help said research are of great interest to BRANZ. The aim is to create a custom implementation of the OSBSS platform customized for BRANZ at a low cost compared to measurement equipment BRANZ currently uses. The Hardware was initially based on the OSBSS, but a different Arduino compatible micro-controller is used to allow memory intensive devices such as displays to be used. The BACON uses four different sensors, which measure temperature, relative humidity, CO2 and Analogue inputs, and the results from comparing the CO2, humidity and temperature sensors showed comparable performance to the sensors and Analyzers BRANZ currently uses. With Power saving methods used, the main Bacon board has an expected battery life of approximately 7 months, and the CO2 Board has an approximate battery life of 2 month with a 1 hour sampling interval. Overall the BACON provides a customized and versatile platform, and at a significantly lower cost in comparison to current sensors and analyzers BRANZ use.

2 Introduction

The health and quality of New Zealand Buildings and housing is an important point of research for Building Research Association of New Zealand (BRANZ), and the rise of low cost, low power micro-controllers and sensors, provides an opportunity to create products that can aid the work BRANZ performs, to provide information which allows the construction industry to improve New Zealand Buildings.

The purpose of this project is to apply the research A.S Ali et al[2] performed on creating a prototype Open Source Building Science Sensors (OSBSS) platform, and customize a solution to the needs of BRANZ, to aid in country wide household air quality research campaigns, over the use of their existing low power data collectors. The end product will provide a platform for future work to improve upon and eventually lead to manufacturing the platform for use by BRANZ in their research.

This report details the findings found creating the low power, low cost Sensor platform named the BRANZ Arduino Collection Operating Node, or simply B.A.C.O.N, and the possible implications this platform can provide for BRANZ.

3 Overview and Design

3.1 Arduino and Software

The hardware concept of BACON was initially based on the OSBSS platform and similarly, the code was developed with the open source Arduino development platform (www.arduino.cc). The design uses a low power ATMEL SMART SAM D21 ARM Cortex-M0+ based 32-bit micro-controller, operating at 48MHz, versus the ATMEL ATmega328p 16MHz 8-bit micro-controller, the OSBSS platform uses, which is a highly popular device among the hobbyist community due to the Arduino platform.

Arduino has a large presence in the development community and thus most hardware available today has libraries written for Arduino, simplifying the process of developing the BACON platform.

The SAM D21 micro-controller was chosen over the smaller ATmega328p due to memory requirements needed to drive a display, since displays usually need a image buffer on the micro-controller, and the ATmega328p used in the OSBSS did not have sufficient amounts of free memory even after optimizing code. The SAM D21 provides 32KB of SRAM (versus 2KB on ATmega328p) which allowed a high resolution display to be used, where the display model was suggested by BRANZ.

An Adafruit Feather M0 Basic Proto pre-made development board, using the SAM D21 micro-controller, was used due to its small footprint compared to other SAM D21 based boards (Arduino M0 and M0 Pro) and uses fewer auxiliary components, allowing lower power consumption to be possible. The SAM D21 micro-controller uses 3.3V only, compared to many 5V Arduino devices on the market, and thus some care must be taken when selecting components as the SAM D21 is not 5V logic tolerant, but most sensors used in the project run on 3.3V or use 3.3V logic.

3.2 Data Storage

The BACON uses two tiers of storage to record time stamped sensor samples to. The first tier is a non-volatile 32KB Ferroelectric RAM (FRAM) module which operates over I2C, and is used as a buffer to build up sample sets before writing to the second tier of storage. The second tier is a micro SD card which operates over SPI, and is the storage medium users can remove and retrieve data from.

The FRAM is used to reduce the time a sample acquisition takes and also provides as a replacement for the SAM D21's lack of EEPROM, which the ATmega328p has built in. The sample period is reduced by removing the overhead SD cards have when they are initialized, which can take up to half a second, by using the FRAM as a sample buffer (which has minimal overhead during initialization in comparison), has virtually unlimited read/write cycles and is faster to store small data sets compared to SD cards. This is due to the way SD cards operate, and the way Arduino SD card libraries mask the exact operation of SD cards, where data is buffered before writing it out to the SD card. The buffering (or delaying writing to SD card) using FRAM also allows the data taken to be more resilient to power loss versus using the microcontrollers SRAM as a buffer.

The FRAM is also used to store configuration data that can be set on-the-fly by a user, rather than recompiling Arduino code, also the configuration data remains if the device is powered off.

3.3 Display

A Display needed to be included in the design, and the Sharp LS027B7DH01 Monochrome Memory LCD display was chosen due to its very low power usage (approximately 350μW while updating the display and 50μW while idle), freely available Sharp Memory Display library from Adafruit, and its high resolution for its relative size (400x240 Pixels in a 2.7 inch diagonal package) can allow detailed data plots in the future. The Display requires a 12000 byte buffer (one bit for each pixel), shares the SPI bus with the micro SD card and real-time clock, and operates at a 2MHz SPI bus speed. The display requires a 5V supply to operate, rather than 3.3V which nearly all other other components use.

Due to this a Texas Instruments TPS60241 Boost charge pump was used due to it only needing four small external capacitors to operate, and the display current consumption was well under the TPS60241's 25mA maximum current draw of the TPS60241. The TPS60241 has better efficiency drop-off at low loads (around 65% efficient with 0.1mA load at 3.3V input) compared to larger inductor based switching boost power converters such as TPS61200 (40% with 0.1mA load at 3.3V).

The Arduino library for Sharp memory displays by Adafruit was modified to use a hardware implementation of SPI available on the SAM D21, rather than a software defined interface, due to hardware SPI already being used by the micro SD card, and a limited amount of available pins on the Feather M0 development board (a software implementation would require 3 extra pins versus one extra pin for display Chip select with the Hardware SPI method).

Since the Sharp display does not include an internal system to prevent DC bias building up within the panel, an external signal (VCOM) must be provided by either software or hardware.

A hardware implementation was chosen since in testing, a software method with fast updates of the screen could occasionally cause image corruption, possibly from the VCOM changing to fast and or irregularly, whereas the hardware implementation would only send the VCOM signal after the display has been updated and also at a more regular interval without the need for constant display updates.

The hardware method uses timer counter 3 in the SAM D21 to invert an output pin whenever a value match occurs in the counter, where the SAM D21's pin is connected to the displays hardware (VCOM) signal pin.

The display is turned on when ever the device is powered on or the keypad is pressed, and stays on for approximately 35-40 seconds before being turned off to save power.

3.4 Time Keeping

The Clock used is the same Real-time clock (RTC) used in the OSBSS platform, the DS3234, which showed low amounts of time drift which A.S Ali et al found [2], also shown in [1], and can operate between 2.0V and 5.5V. The DS3234 RTC shares the SPI bus with the micro SD card and Display, where the SPI bus operates at 2MHz for the RTC, which is below the 4MHz maximum bus speed supported.

Unlike the Micro SD card and display, which uses the same SPI transfer mode (Mode 0), the Real-time clock uses a different clock phase (SPI mode 1), which can cause issues with reading the time if not handled correctly.

The DS3234 features a backup battery system, allowing the time to be kept even if the main battery is discharged/disconnected, an alarm system, which provides a wake signal to the micro-controller at specific times, and an internal temperature compensation, which corrects for deviations in its crystal oscillator due to changes in temperature. The alarm feature is used to wake up the micro-controller and sample data from the various sensors, and external sensors can have sample times independent from the main device's sensors.

3.5 Sensors

The Sensors Used are the Sensirion SHT15 Temperature and Humidity sensor, a Silicon Labs Si7051 digital temperature sensor, A Texas Instruments ADS1115 16-bit I2C Analogue to Digital Converter (ADC) and a SenseAir K30 STA CO2 concentration sensor.

The Sensirion SHT15 has an accuracy of ±2% for relative humidity (RH) and with ±0.3°C for temperature, which is used to calculate the RH. This sensor uses a two wire serial interface to send data, where the two wire interface is simulated in software on the micro-controller. The SHT15 was chosen due to its performance[2]. Newer versions of the SHT15 exist, such as the SHT35, which uses I2C instead.

The Silicon Labs Si7051 digital temperature has a ±0.1 to 0.25°C accuracy and uses I2C to communicate with the micro-controller, which is preferred due to using fewer pins than separate Serial interfaces or using dedicated ADC pins on the SAM D21.

The Texas Instruments ADS1115 16-bit 4 channel I2C ADC was included for using external analogue sensors and possibly thermocouples, where the ADS1115's 16x Programmable Gain Amplifier can give a minimum resolution of 7.8125μV, and two channels can be combined to measure differential voltages.

Finally, the SenseAir K30 STA CO2 Gas sensor, with an accuracy of ±30 ppm with ±5% of a reading at normal atmospheric pressure when calibrated with a reference gas with a ±2% accuracy. The K30 was chosen due to its performance in the OSBSS[2] and its relative cost compared to SenseAirs more advanced offerings. The K30 has no power saving features, has a sample rate of 2 seconds which cannot be reduced, and a warm-up time of 2 minutes after being switch on to give reliable readings. Due to this it is run from a different power supply/battery.

3.6 Power Saving

While the SAM D21 is a low power micro-controller, running continuously at 48MHz the Feather M0 board draws approximately 10.5mA (which is higher than the ATmega328p's 6mA current draw).

To increase battery life, the average current drawn must be minimized, thus using sleep modes allows the average current draw to decrease. But while current draw in sleep modes is a large contributor to overall power draw [3], the proportion of time spent asleep versus at full power has a large effect on power consumption, as shown in Figure 2, where the time spent taking a sample is fixed, and the time between samples is varied.

The SAM D21 has four levels of sleep modes, where each lower level decreases power consumption at the cost of functionality. The Two lowest sleep modes are used in the BACON where only an asynchronous interrupt can wake up the device, and the lowest state disables the clocks to all of the internal function blocks. The lowest power state is used when the device is idle with the display switched off, and waiting for an interrupt from either the RTC or keypad.

The second lowest sleep state is currently used while the display is active, and allows the clock

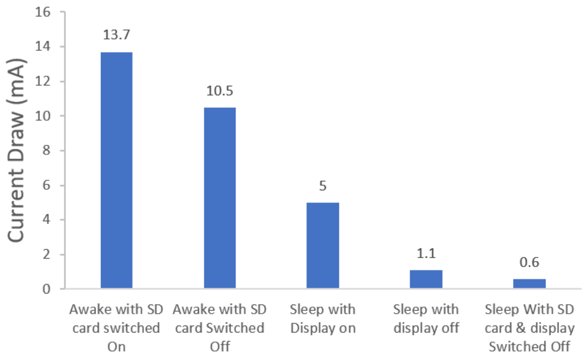

Figure 1: Current draw of the system in different power states

source to the timer counter modules to be active, but due to an unknown interrupt source or issue with the code, the SAM D21 wakes up almost immediately after entering sleep mode while the display is on. This increases the current draw while the counter is enabled from 1mA to 5mA. Due to limited time and the irregular, short time the display would be on for, the current draw was decided to be negligible for this revision of the BACON.

In the lowest sleep mode state, with display turned off, the average measured current draw was 0.6mA, but fluctuated by up to 0.15mA. Other Feather M0 boards exhibited lower average current draws around 0.5mA and also fluctuated, but taking into account the data sheet for the SAM D21 states a maximum current draw of 12.8μA at 25°C in the lowest sleep state, there is possibly inherent inefficiencies in the Feather Board designs for low power operation and or improper configuring of pins in sleep mode contributing to the observed current draws.

Current consumption in these different states was measured and shown in Figure 1, and due to fluctuations and higher than expected current draw in the lowest sleep state, along with limited numbers of pins available on the Feather board, the on-board sensors and FRAM would not be switched off during sleep. It was found that they only contributed to 10-20μA while sleeping, which is negligible in comparison to the overall sleep current draw (although the hardware already has the components to enable switching power to these parts, if Pin availability is alleviated and PCB is revised).

The K30 CO2 sensor has an average current draw of 62mA. In order to reduce the average current, the K30 is powered by a TI TPS61200 boost converter which has its enable pin by default pulled down to ground. This means power to the K30 is off by default, and only gets switched on by the SAM D21 when needed.

3.7 Expected Battery Life

Using the data from figure 1, the battery life can be estimated, along with the effect of using the FRAM as a buffer. Assuming worst case scenarios, the time for a sample to finish and the BACON to resume sleeping is approximately 1.5 seconds, the extra time taken if bypassing the FRAM buffer and writing each sample to SD card is 0.5 seconds (due to initializing SD card each time), and inefficiencies from losses assumed to be roughly 30%, the expected battery life is approximately 7 months using a 6000mAh Lipo and the FRAM buffer provides an extra 2-10% longer run time depending on the sampling interval.

The equation for finding the approximate battery life is (assuming 60 second sampling rate, 1.5 sec sample time and a FRAM buffer of 512 samples long is used):

Run time in Hours =

$$\left(\left(\frac{58.5s}{60s}\times 0.6mA\right)+\left(\frac{1.5s}{60s}\times 10.5mA\right) + \left(\frac{0.5s}{60s\times 512}\times 30mA\right)\right)\div(6000mA\times 0.7)$$
$$= 3111\ hours\ (\approx 4\ months)$$

If the sleep mode current is reduced to 0.2mA, a smaller battery can be used, as shown in figure 4, and the benefits of using the FRAM buffer are more obvious, as over the same sample period the FRAM can provide 10-20% longer battery life. Thus improvements to the sleep mode current draw of the BACON (either by software or hardware revisions) increase the benefits of using the FRAM buffer.

The battery life of the K30 CO2 sensor is determined by the sampling rate used, as no measurable current was observed while the TPS61200 boost converter was disabled, thus the time spent off is highly important in providing long battery life for the CO2 sensor, shown in figure 3.

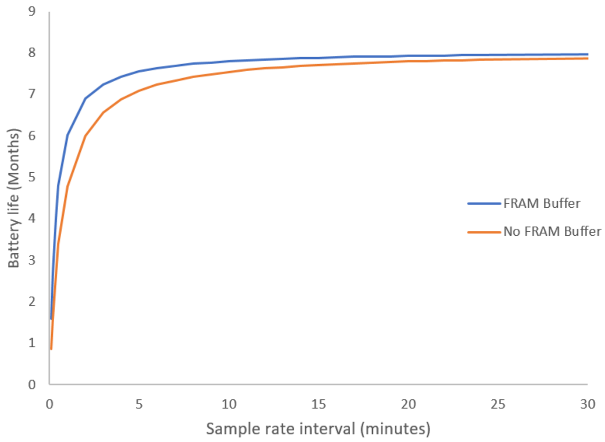

Figure 2: Estimated Battery Life vs. Sample Interval, with and without use of an FRAM buffer, using 6000mAh battery.

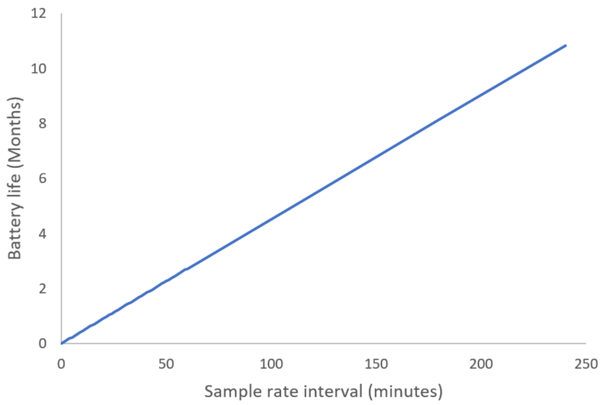

Figure 3: Estimated Battery Life vs. Sample Interval for K30 CO2 Sensor using 6000mAh battery and minimum ON time of 2 minutes per sample interval.

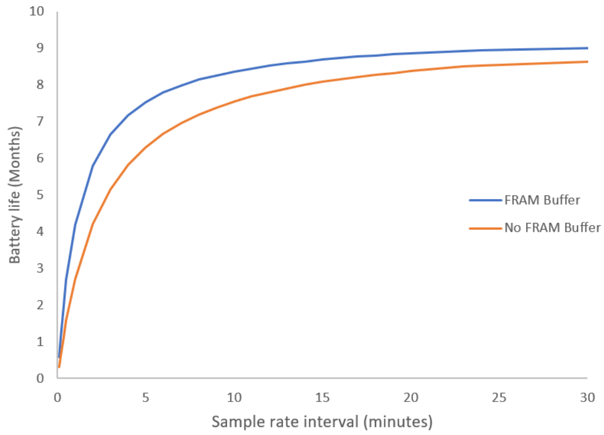

Figure 4: Estimated Battery Life vs. Sample Interval, with sleep current of 0.2mA, along with and without use of an FRAM buffer, using 2000mAh battery .

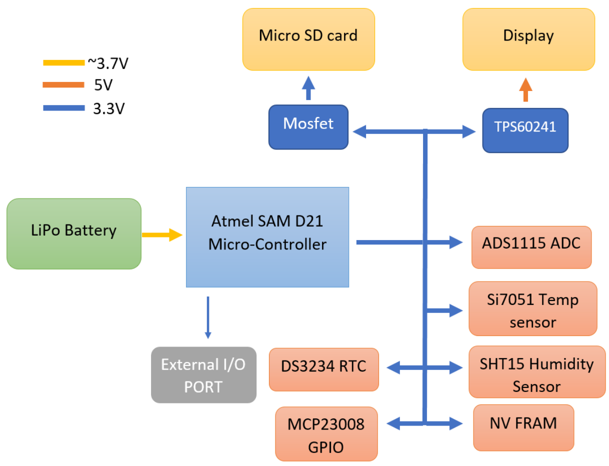

Figure 5: Diagram of Voltages supplied to each device on the Main Board of the BACON.

3.8 Electrical layout

All components operate on 3.3V supplied by the Feather M0 boards regulator, apart from the Shap Memory display and SenseAir K30 as they operate on 5V as shown in figure 5 and 6, thus the Display uses a TPS60241 boost converter and the SenseAir K30 uses a TPS61200 boost converter. these converters supply regulated 5V, and have enable pins which are used to turn off the display and SenseAir K30.

Four different interfaces are used to connect all devices to the micro-controller, which are I2C, SPI, UART and General Purpose Input and Output (GPIO), which is shown in Figure 7. The external I/O port on the main Board of the BACON has two wire UART, I2C and GPIO interfaces to allow external sensors to be connected, such as the CO2 board made for the SenseAir K30 (Figure 11 & 12). The GPIO lines, with respect to the CO2 Board, are used to enable/disable the SenseAir k30's boost converter, check the value of the K30's status pin and determine which data interface the CO2 board

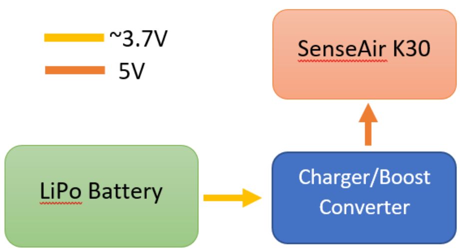

Figure 6: Diagram of Voltages supplied to the SenseAir K30 STA on the CO2 Board.

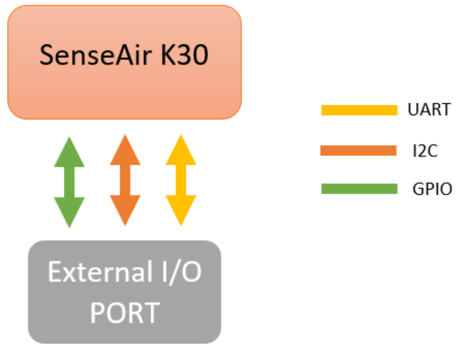

Figure 8: Diagram of Interconnects used on the CO2 Board of the BACON.

is using via a GPIO line being pulled up to 3.3V, which means I2C is used, or down to ground which means UART is used.

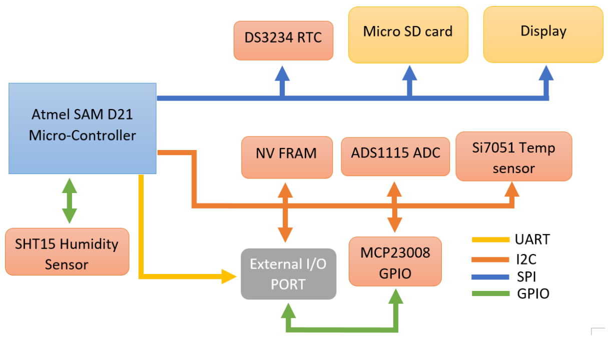

Figure 7: Diagram of Interconnects used on the Main Board of the BACON.

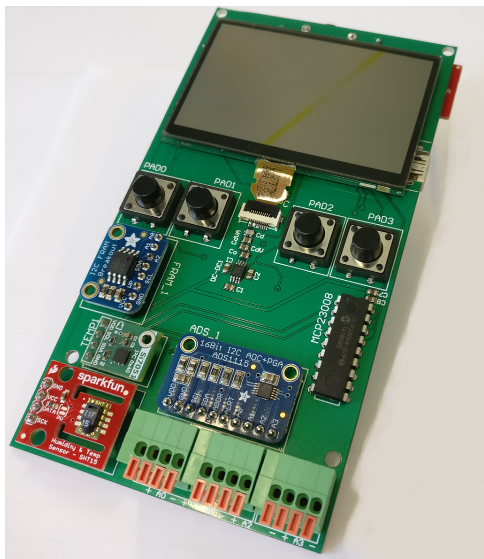

Figure 9: Front Image of the BACON main board.

While UART and I2C are shown in figure 8, only either I2C or UART connection type can be used by the SenseAir K30, not both. I2C and UART are available on the CO2 board due to future compatibility with different sensors, or if one connection method fails on the K30, as it is easily damaged by static electricity.

3.9 Final Product Design

The final design for the BACON that was achieved is shown in figures 9, 10, 11 and 12, and has dimensions of 130x70mm for the Main board and 100x55mm for the CO2 Board.

The front of the main board shows the Si7051 and SHT15 sensors in the lower left corner and the spring connectors in the lower right for the ADS1115 ADC, the display on top and underneath it is the keypad used to navigate the configuration menus.

The back of the Main board (figure 10) shows the Feather M0 board, DS3234 RTC with backup battery, micro SD card holder, external I/O port, Power switch at the top and finally the battery connector in between the Feather board and DS3234

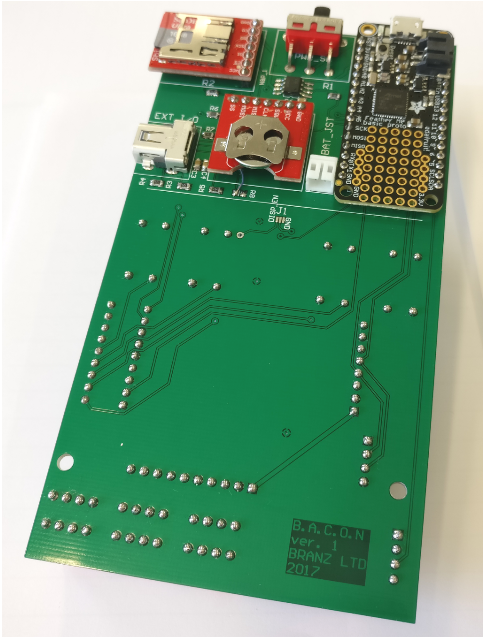

Figure 10: Back Image of the BACON main board.

RTC. The external I/O port was chosen to use a Mini DisplayPort connector due to the number of pins available, small size of the connector, availability of cables and low voltages (3.3V) the DisplayPort standard uses in comparison to USB type c cables (5V+). Other cable types such as Serial (RS-232 etc.) and ribbon cables were not used due to their physical size, as future versions of the BACON may be smaller and not have room for such connectors.

A space is provided on the back, free of components, for a 6000mAh battery to be positioned. The solder point for the components on the front are filed down and rounded to prevent possible injury from removing/disconnecting the batteries, as well as reducing the chance of puncturing the main battery (which should be mounted with spacers or thick double sided tape just in case).

The front of the CO2 board (figure 11) holds the external I/O connector, power switch and the SenseAir K30 sensor, which is mounted using spacers so only screws are used to hold it in place as no mechanical stress/flex should be applied to the K30 (which can result in a reduction of accuracy).

The back (figure 12) shows the battery charger

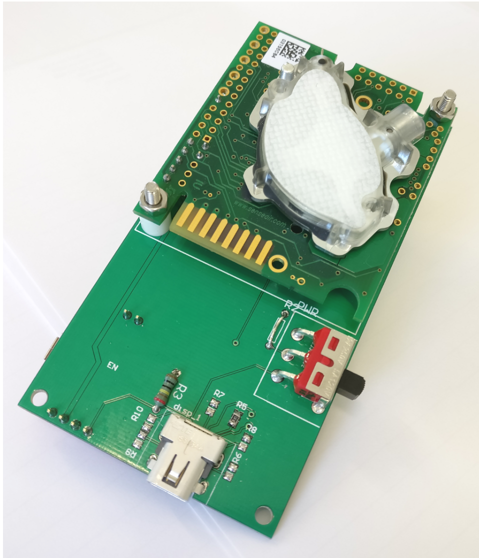

Figure 11: Front Image of the BACON CO2 board.

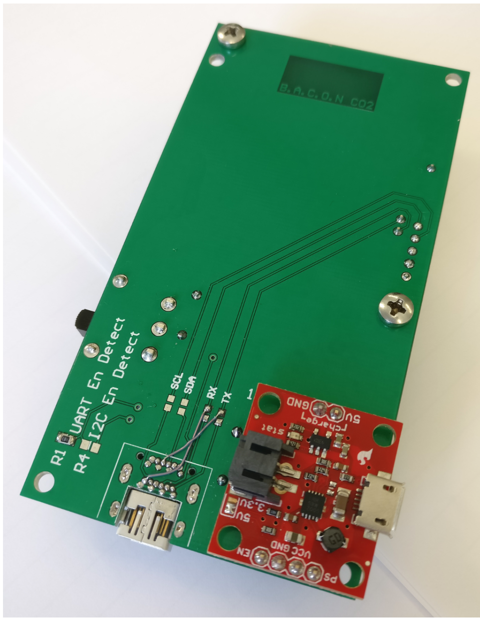

Figure 12: Back Image of the BACON CO2 board.

booster used from www.Sparkfun.com which uses the TPS61200, and the surface mount resistor pads which are used to configure the interface mode. Note that the board version pictured had a wiring issue where the I2c and UART PCB traces were connected to the external I/O port incorrectly, and was fixed by soldering several bypass wires. The back also provides a place for a 6000mAh battery to be positioned.

The CO2 board is connected to the main board with a standard Mini DisplayPort cable via the external I/O port. Although a DisplayPort cable/connector is used, the system is not compatible with any other DisplayPort OR thunderbolt capable systems. The cable is only used to carry I2c, UART and GPIO lines to external add-on sensor boards, and connecting either board to a DisplayPort or thunderbolt system may damage the BACON and or connected system. Although, some effort has been made to protect either device from connection to a DisplayPort system, Thunderbolt connections will permanently damage the BACON as it uses 16V signals instead.

4 Sensor Testing methodology

Sensirion SHT15, Silicon Labs Si7051 and SenseAir K30 were tested against BRANZ's humidity, temperature and gas analyzer equipment used in BRANZ research.

The SHT15 sensor was compared by placing the BACON in a humidity controlled chamber, starting at 50% RH and increasing in 10% steps to 80% RH approximately every 20-30 minutes, measuring humidity with an EasyLog TH+ and the BACON every two minutes.

The Si7051 temperature sensor was compared by placing it in a thermal insulation test chamber with a starting temperature of 10°C and increasing in 5°C steps to 35°C every 40 minutes, and recording the Si7051 sensors readings every two minutes for each temperature step.

Finally the SenseAir K30 was tested by placing it in a 1m^3 test chamber and filling it with CO2 gas. A fan was placed in the chamber to ensure the CO2 is equally distributed throughout the test, and a small vent in the chamber is left open to allow the CO2 levels to decay and provide a wide range of values to compare. The CO2 concentration measurements were compared to a calibrated Gas Analyser which samples the gas from in front of the K30, and both take CO2 samples every five minutes.

The test was ran twice to also compare results for leaving the CO2 sensor on for the whole test versus for allowing the CO2 sensor to be switched off while it is not needed for power savings.

5 Sensor Testing Results

The Temperature results showed a range of variations but was within the ±0.1-0.3°C range specified in the Si7051 data sheet, where the highest delta from the thermal test chamber was -0.29°C below the average temperature in the chamber at 15°C as shown in Figure 13.

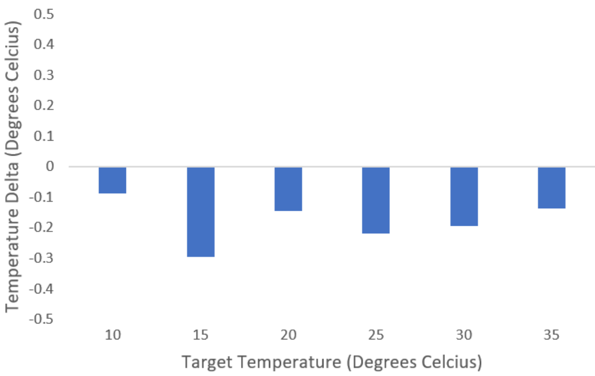

Figure 13: Si7051 sensor temperature differences from Thermal test chamber at different temperatures.

The Humidity results showed the SHT15 having very similar readings to the EasyLog TH+ shown in figure 14, but increases in comparison as the humidity rises, reaching up to 3.5% higher at 80%RH in figure 15. Note in figure 14 and 15 that the low starting humidity of the BACON was due to placing it in the humidity chamber which had a higher humidity than ambient outside the chamber. Due to the EasyLog TH+ having an accuracy of ±2% RH, the delta results in figure 15 could be up to 4% between the two sensors, while still being within 2% of the actual RH.

The CO2 comparisons show the Calibrated gas analyzer and SenseAir K30 STA to be very close in Figure 16, getting down to a delta of 75-50 $\mu g/m^3$ around normal CO2 level of approximately 1000 $\mu g/m^3$, and switching off the K30 between Sampling seems to have no impact on the accuracy of

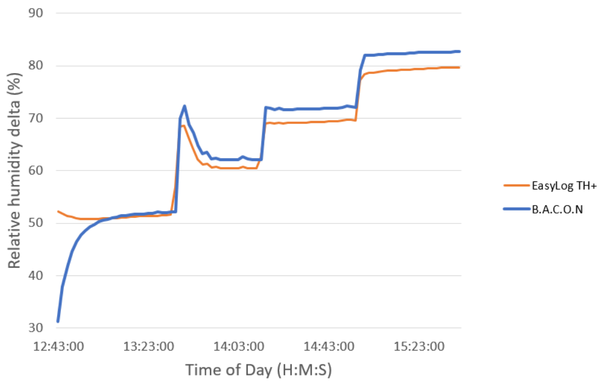

Figure 14: Comparison of EasyLog TH+ to Sensirion SHT15 Humidity sensor in a controlled test chamber.

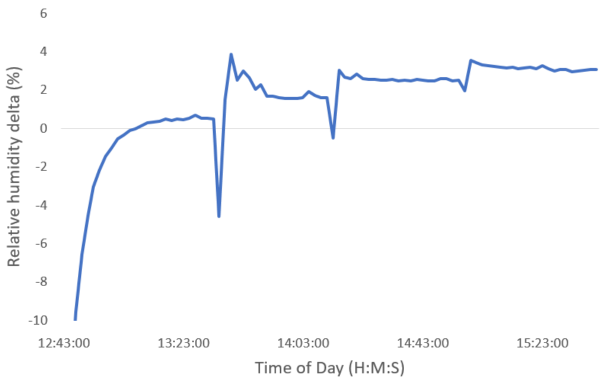

Figure 15: Relative humidity Difference between EasyLog TH+ to Sensirion SHT15 Humidity sensor in a controlled test chamber.

measurements, as figure 16, 17, 18 and 19 show the same patterns and deltas. Note that the Power saving CO2 tests results start at a lower CO2 concentration of 2000 $\mu g/m^3$ versus 4000 $\mu g/m^3$.

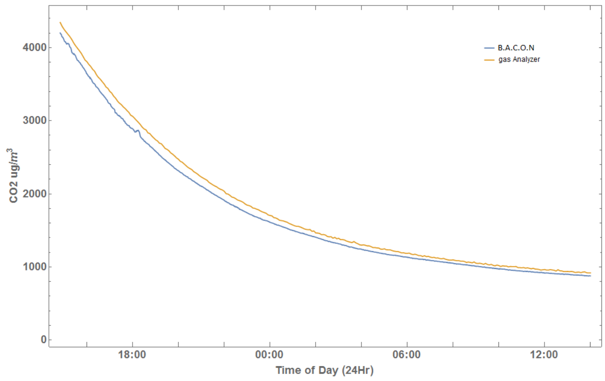

Figure 16: CO2 concentration, in $\mu g/m^3$, comparison between Calibrated Gas Analyser and SenseAir K30 STA for a decay profile of CO2 concentrations in a $1m^3$ test chamber.

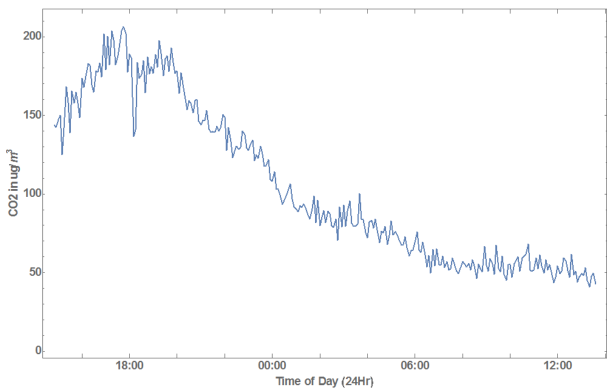

Figure 17: CO2 concentration difference, in $\mu g/m^3$, between Gas analyser and SenseAir K30 STA over a CO2 decay profile.

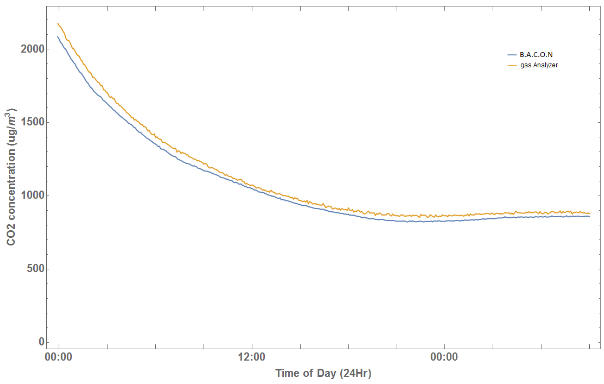

Figure 18: CO2 concentration, in $\mu g/m^3$, comparison between Calibrated Gas Analyzer and SenseAir K30 STA for a decay profile of CO2 concentrations in a $1m^3$ test chamber, with power saving techniques applied to SenseAir K30 STA.

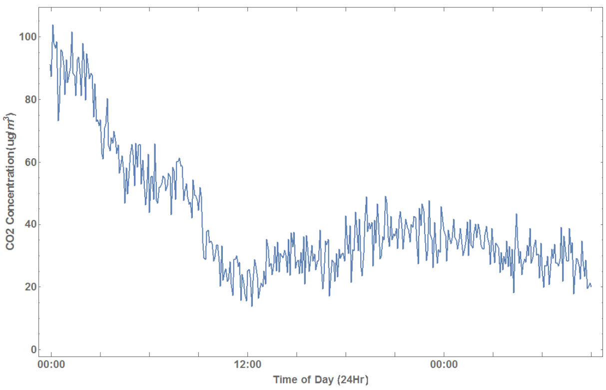

Figure 19: CO2 concentration difference, in $\mu g/m^3$, between Gas analyzer and SenseAir K30 STA over a CO2 decay profile, with power saving techniques applied to SenseAir K30 STA.

6 Discussion

The results from comparing the sensors shows the Si7051 temperature sensor and SHT15 humidity sensor operate within their stated accuracy range, where the Si7051 showed no significant trends in performance and the SHT15 results suggested the accuracy reduces as the relative humidity increases, but the accuracy of the EasyLog TH+ must be accounted for, thus a definitive answer on the results can not be made reliably below $\pm 4\%$ RH (in comparison to the EasyLog TH+).

The SenseAir K30 CO2 sensor also shows consistent performance weather it is allowed to run continuously or is switched off between use, and provide relatively accurate readings for low power CO2 sensors. The testing results showed a trend where higher differences between the Gas Analyzer and SenseAir K30 occurred at higher CO2 concentrations, up to three times the K30's accuracy of ± 30 ppm ($60\mu g/m^3$), and reduces when operating in environments with CO2 concentrations of 2000 $\mu g/m^3$ or less, but otherwise follows exactly the performance of the significantly more expensive Gas Analyzer (several orders of magnitude) used for comparison.

7 Limitations

The CO2 results are achieved with factor calibrations, and the K30 is able to be manually calibrated, either with software or via hardware pins, but the software of the BACON currently does not have the capability to calibrate the SenseAir K30. Another limitation with the CO2 sensor is where occasionally if the K30 is repeatedly powered on and off too quickly, it may cause self diagnosis errors to trigger, preventing the K30 from operating. The only solution in such cases is to power down the K30 for at least 2-5 minutes before powering back on.

During a test, an anomaly with the recording of the CO2 readings were observed, where the time stamp and CO2 reading were corrupted, as shown by the limited range in figure 18 compared to figure 16, but the time stamps for the rest of the sensors were correct. This possibly may be caused by the CO2 sensor previously being power cycled rapidly before the test. The issue corrected itself during testing and was not observed for the rest of the test.

Currently a graph of the recorded readings from each sensor is not able to be shown on the display as there was not enough time to incorporate it.

The high sleep currents were found when testing different Feather development boards to differ by up to $600\mu A$, and further work will be needed to reduce the current draw down to lower levels. Also due to the high sleep current, a 6000mAh battery is used, but if sleep current draw can be reduced, a smaller and cheaper 2000mAh battery could be used, while still maintaining the same 7 month run time. Although if 7 months is longer than needed, a 2000mAh battery can provide up to a 2.5 month run time in its current state.

The battery life for the CO2 Board is limited directly by how often a sample is needed, and apart from reducing the warm up time (not recommended below 1 and a half minutes) used or replacing the sensor with a more expensive and lower power model, the battery life can only be extended by using a larger battery than the 6000mAh lithium ion pack currently used, or increasing the CO2 sampling period.

Alternatively, both the CO2 board and Main board can be run off of an external USB power supply, with the exception that the CO2 board must have a battery connected to operate from external power.

8 Conclusion

Overall the BACON provides a customized and versatile platform in comparison to current sensors BRANZ uses. When compared to conventional Bench-Top analysis equipment which BRANZ currently employs, at an overall significantly lower cost, the BACON provides a relatively small reduction in performance, while running on Open source software inspired by the OSBSS platform [2].

9 Acknowledgments

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10 Appendix

Table 1: Cost Breakdown

Make/Model	Accuracy	Unit Cost
Adafruit Feather M0 Basic Proto	-	$29.00
6000mAh Li-ion battery	-	$62.00
MCP23008 GPIO expander	-	$4.00
Adafruit I2C FRAM Breakout	-	$15.00
Adafruit ADS1115 ADC Breakout	-	$23.00
Sparkfun Sensirion SHT15 Breakout	$\pm$3% RH	$69.00
Si7051 breakout	$\pm$0.1-0.3°C	$13.00
SenseAir K30 STA CO2 Sensor	$\pm$30 ppm	$125.00
Sparkfun DS3234 RTC breakout	-	$24.00
Sparkfun Level Shifting Micro SD card Breakout	-	$8.00
Sparkfun LiPo charger/Booster Breakout	-	$8.00
Sharp LS027B7DH01 TFT memory Display	-	$54.35
Mini Displayport connector	-	$3.72
TI TPS60241 DC-DC converter	-	$2.45
Molex FFC/FPC connector	-	$1.10
Sharp LS027B7DH01 TFT memory Display	-	$54.35
Power Switch	-	$4.26
push button switch	-	$1.00
JST battery connector	-	$2.00
Spring terminals	-	$2.50
ROHM SP8M21FRATB P and N channel Mosfet	-	$2.28
Short Male headers	-	$7.00
Miscellaneous SMD Capacitors & Resistors	-	$3.00
PCB Prototype	-	$250.00

References

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