Mission Space Lab Phase 4 Report

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Chosen theme: Life in Space

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Introduction

When we began researching for an experiment idea we came across a picture of astronaut Chris Hadfield on ISS playing guitar in shorts which led us to wonder how hot it really feels on ISS (heat index).

It turns out apparent temperature is an important factor in demanding environments like on board ISS because it can decrease motor skills and mental performance thus making completing tasks and avoiding errors more difficult.

Our goal is to find out heat index from on-board temperature, pressure and humidity by means of psychrometric calculations**.**

For a known humidity level on ISS of around 60% we expect the heat index (HI) to be lower than 28ºC (actual temperature being ≤27ºC or ≤80F) since higher values could pose a threat to crew safety and efficiency (Fig-5).

Method

Our code recorded CPU temperature and sensor-hat readings for temperature, humidity and pressure about every 10 seconds into a csv file. Meanwhile the LED matrix showed different patterns as feedback.

Due to CPU temperature, the sense-hat performs inaccurately (Fig-1) when attached just on top of RaspberryPi so back on Earth we needed to work out a way to tell how far apart AstroPi readings are from the actual values.

In order to get reliable readings to compare sense-hat data with, we've tested a DHT22 sensor against a type K thermocouple (Fig-2) and data from the local weather station (WS-Torredembarra).

From the data series gathered we concluded that the DHT22 sensor performs broadly within specifications.

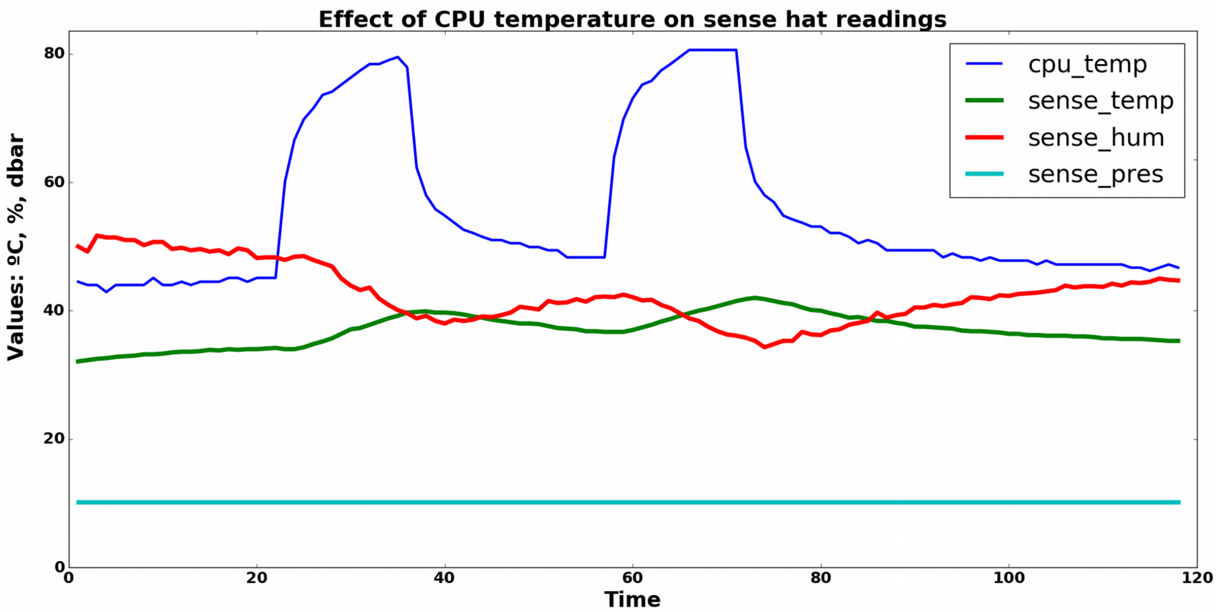
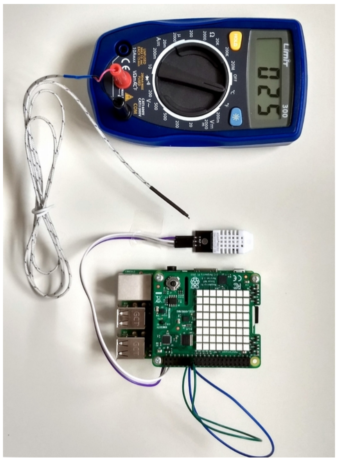


Fig-1: Stress testing CPU (sysbench tool) shows the influence of CPU temperature on sense-hat readings



TIME	DHT Temp	DHT Humid	WS Temp	WS Humid
20200522-090001	21,1	75,1	22,8	76
20200522-101454	22,2	75,2	23,6	78
20200522-110025	22,7	78,6	24,7	78
20200522-120028	23,4	82,4	24,7	80
20200522-130002	23,9	76,4	24,9	76
20200522-140005	25,3	66,8	25,3	72
20200522-150009	25,1	74,9	24,8	72
20200522-160012	26,6	65,2	25,0	74

Fig-2: DHT22 calibration setup on the RaspberryPi 3B from AstroPi kit and data from DHT22 and WS

Measuring simultaneously, sense-hat gets about 6 degrees over and 14 points under DHT22 corresponding values for temperature and humidity (Fig-3).

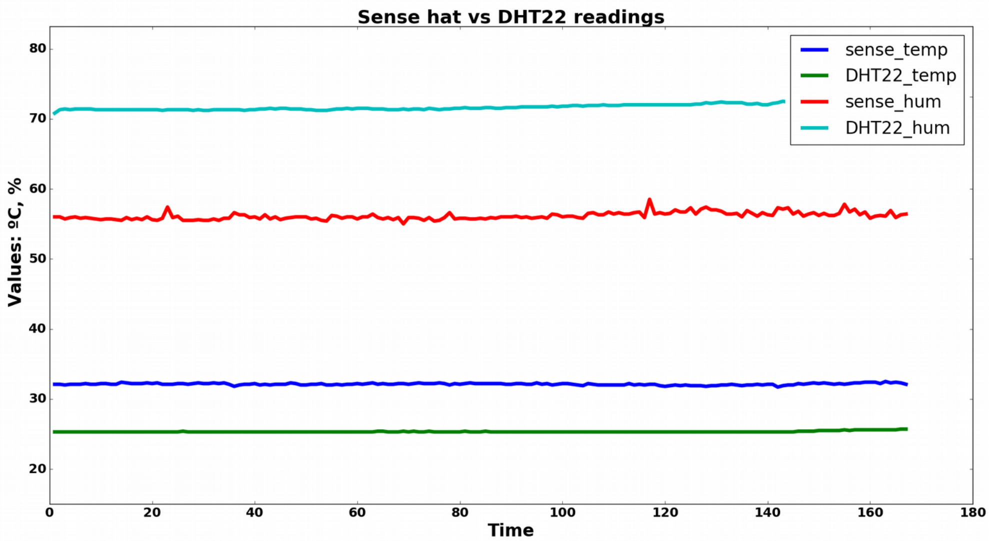


Fig-3

Since AstroPis are model B+, subtracting or adding the aforementioned differences doesn't make much sense. Instead the CPU effect could be taken into account to calculate correction factors for both magnitudes. This is what it would look like for temperature

$$DHT\_temp = sense\_temp - \frac{(cpu\_temp - sense\_temp)}{\boldsymbol{temp\_factor}} \rightarrow$$

$$\rightarrow \boldsymbol{temp\_factor} = \frac{(cpu\_temp - sense\_temp)}{(sense\_Temp - DHT\_Temp)}$$

Finally, the factored T and H values are fed into a HI formula. For the sake of simplicity we've chosen the Australian APPARENT TEMPERATURE over NOAA's HEAT INDEX and CANADIAN HUMIDEX.

$$AT = T_a + 0{,}33 \cdot \rho - 0{,}70 \cdot ws - 4{,}00$$

$$\rho = \frac{rh}{100} \cdot 6{,}105 \cdot e^{\frac{(17{,}27 \cdot T_a)}{(237{,}7 + T_a)}}$$

AT is the Apparent Temperature in ^{o}C

- $\mathbf{T_a}$ is the Dry bulb Temperature in ^{o}C
- **ρ** is the water vapor pressure (hPa)
- **ws** is the wind speed (m/s)
- **rh** is the Relative Humidity (%)

Results

From AstroPi data we've got average CPU temperature, sense-hat temperature and humidity values of

av. cpu_temp: 30,4ºC
av. sense_temp: 26,26ºC
av. sense_hum: 42,28%

From our testing series we've got average temperature and humidity factors values

av. temp_factor: 2,13
av. hum_factor: 0,78

We use this data to find factored temperature and humidity

$$Factored\_temp = sense\_temp - \frac{(cpu\_temp - sense\_temp)}{temp\_factor} = 26{,}26 - \frac{(30{,}4 - 26{,}26)}{2{,}13} = \mathbf{24{,}32\ ^{o}C}$$

$$Factored\_hum = sense\_hum - \frac{(cpu\_temp - sense\_hum)}{hum\_factor} = 42{,}28 - \frac{(30{,}4 - 42{,}28)}{0{,}78} = \mathbf{57{,}51\ \%}$$

Finally, from the factored values we find out apparent temperature either using the formulas or looking up the table (Fig-4). As for air speed we assumed a minimum of 0,5 m/s (forced air circulation).

$$\rho = \frac{57{,}51}{100} \cdot 6{,}105 \cdot e^{\frac{(17{,}27 \cdot 24{,}32)}{(237{,}7 + 24{,}32)}} = 17{,}44$$

$$AT = 24{,}32 + 0{,}33 \cdot 17{,}44 - 0{,}70 \cdot 0{,}5 - 4{,}00 = \mathbf{25{,}72\ ^{o}C}$$

Apparent temperature (AT) from temperature and relative humidity - after Steadman 1994

Relative Humidity (%) \ Temperature (°C)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
0	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
5	16	17	18	19	20	21	22	23	24	25	26	28	29	30	31	32	33	34	35
10	17	18	19	20	21	22	23	24	25	26	27	28	29	31	32	33	34	35	36
15	17	18	19	20	21	22	24	25	26	27	28	29	30	31	33	34	35	36	37
20	17	18	20	21	22	23	24	25	26	28	29	30	31	32	33	35	36	37	38
25	18	19	20	21	22	24	25	26	27	28	29	31	32	33	34	36	37	38	40
30	18	19	21	22	23	24	25	26	28	29	30	31	33	34	35	37	38	39	41
35	19	20	21	22	23	25	26	27	28	30	31	32	34	35	36	38	39	40	42
40	19	20	21	23	24	25	26	28	29	30	32	33	34	36	37	39	40	41	43
45	19	21	22	23	24	26	27	28	30	31	32	34	35	37	38	40	41	43	44
50	20	21	22	24	25	26	28	29	30	32	33	35	36	38	39	41	42	44	45
55	20	22	23	24	25	27	28	30	31	32	34	35	37	38	40	42	43	45	46
60	21	22	23	25	26	27	29	30	32	33	35	36	38	39	41	42	44	46	48
65	21	22	24	25	27	28	29	31	32	34	35	37	39	40	42	43	45	47	49
70	21	23	24	26	27	28	30	31	33	35	36	38	39	41	43	44	46	48	50
75	22	23	25	26	28	29	31	32	34	35	37	38	40	42	44	45	47	49	
80	22	24	25	27	28	30	31	33	34	36	38	39	41	43	45	46	48	50	
85	23	24	26	27	29	30	32	33	35	37	38	40	42	44	45	47	49		
90	23	25	26	28	29	31	32	34	36	37	39	41	43	45	46	48	50		
95	23	25	26	28	30	31	33	35	36	38	40	42	43	45	47	49			
100	24	25	27	29	30	32	33	35	37	39	41	42	44	46	48	50			

Fig-4: Apparent temperature

NOAA national weather service: heat index

Relative humidity \ Temperature	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	86 °F (30 °C)	88 °F (31 °C)	90 °F (32 °C)	92 °F (33 °C)	94 °F (34 °C)	96 °F (36 °C)
40%	80 °F (27 °C)	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	94 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)
45%	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	87 °F (31 °C)	89 °F (32 °C)	93 °F (34 °C)	96 °F (36 °C)	100 °F (38 °C)	104 °F (40 °C)
50%	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	99 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)
55%	81 °F (27 °C)	84 °F (29 °C)	86 °F (30 °C)	89 °F (32 °C)	93 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	106 °F (41 °C)	112 °F (44 °C)
60%	82 °F (28 °C)	84 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	110 °F (43 °C)	116 °F (47 °C)
65%	82 °F (28 °C)	85 °F (29 °C)	89 °F (32 °C)	93 °F (34 °C)	98 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	114 °F (46 °C)	121 °F (49 °C)
70%	83 °F (28 °C)	86 °F (30 °C)	90 °F (32 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	112 °F (44 °C)	119 °F (48 °C)	126 °F (52 °C)
75%	84 °F (29 °C)	88 °F (31 °C)	92 °F (33 °C)	97 °F (36 °C)	103 °F (39 °C)	109 °F (43 °C)	116 °F (47 °C)	124 °F (51 °C)	132 °F (56 °C)
80%	84 °F (29 °C)	89 °F (32 °C)	94 °F (34 °C)	100 °F (38 °C)	106 °F (41 °C)	113 °F (45 °C)	121 °F (49 °C)	129 °F (54 °C)	
85%	85 °F (29 °C)	90 °F (32 °C)	96 °F (36 °C)	102 °F (39 °C)	110 °F (43 °C)	117 °F (47 °C)	126 °F (52 °C)	135 °F (57 °C)	
90%	86 °F (30 °C)	91 °F (33 °C)	98 °F (37 °C)	105 °F (41 °C)	113 °F (45 °C)	122 °F (50 °C)	131 °F (55 °C)		
95%	86 °F (30 °C)	93 °F (34 °C)	100 °F (38 °C)	108 °F (42 °C)	117 °F (47 °C)	127 °F (53 °C)			
100%	87 °F (31 °C)	95 °F (35 °C)	103 °F (39 °C)	112 °F (44 °C)	121 °F (49 °C)	132 °F (56 °C)			

Key to colors: Caution, Extreme caution, Danger, Extreme danger

Fig-5: NOAA Heat Index thermal discomfort

Conclusion

The results match our initial hypothesis in that apparent temperature is well below 28ºC (Fig-5). Despite that fact, we are not extremely confident about the accuracy of the final number because the method used doesn't come without shortcomings.

First, we don't know the flight case dissipation capabilities or the effect of space-hardening treatment on the sense-hat sensors. And second, we run the tests on a Raspberry Pi 3B from the Astro Pi kit whereas actual AstroPIs are model B+.

All in all though, we could confirm that ISS crew work in conditions of thermal comfort since resulting AT is beyond "caution area" regarding thermal stress (Fig-5).

We've also noticed that sense-hat performs better outdoors and when mounted with a stacking header instead of simply attached on top of the raspberry.

Unfortunately, we learnt too late about the get_temperature_from_humidity and get_temperature_from_pressure functions so they didn't get into the code.

Nevertheless, we've learnt a lot and now feel encouraged to do more extensive testing on sense-hat performance.

Finally, we would like to thank ESA and RaspberryPi for giving us such an amazing opportunity.

And also special thanks to Josep Palau for mentoring us through this challenge.

Project data and code can be found at:

https://github.com/jpalau-edu/AstroPi1920/tree/master/PiNuts