Improved Contact Tracing for COVID-19

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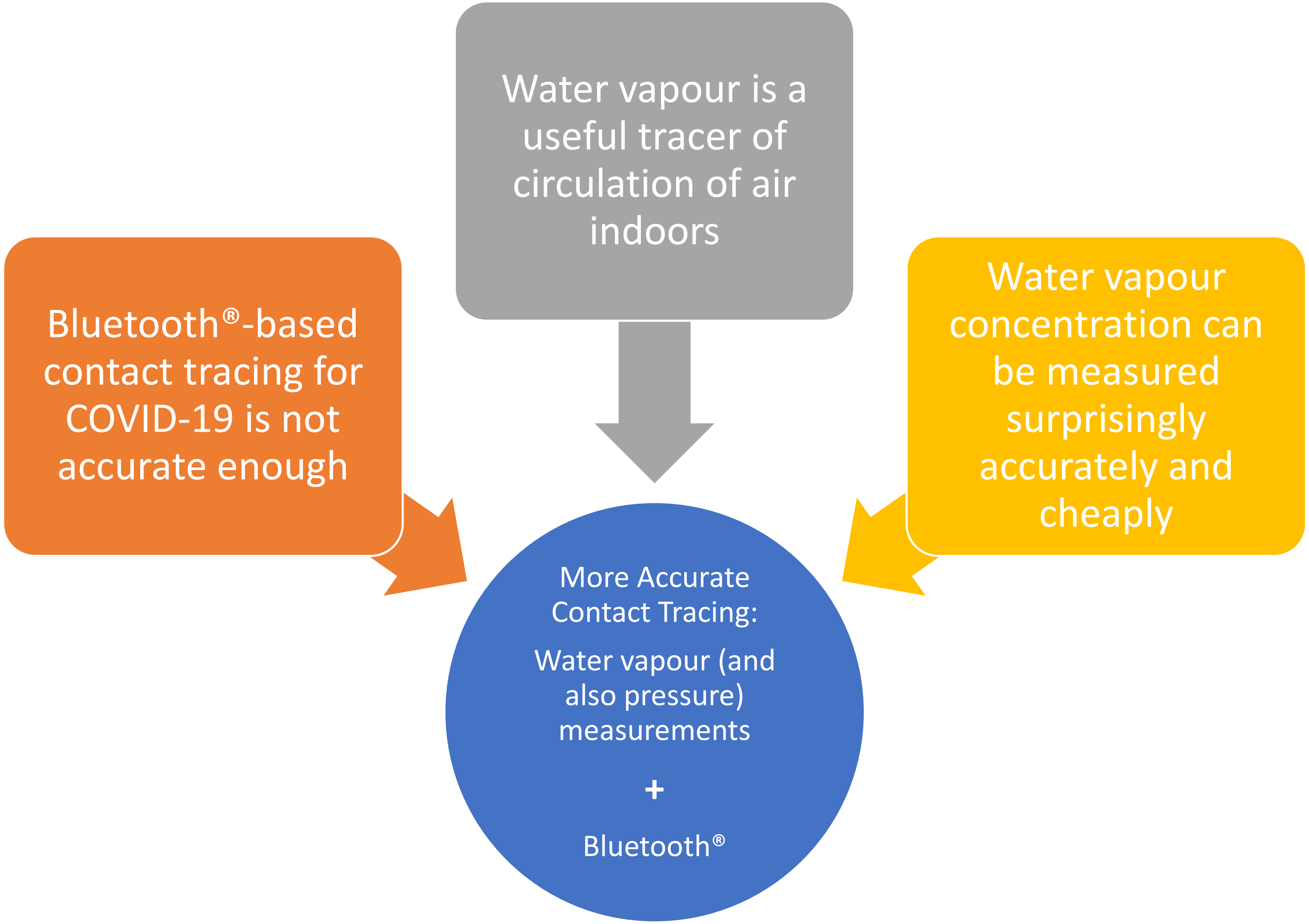
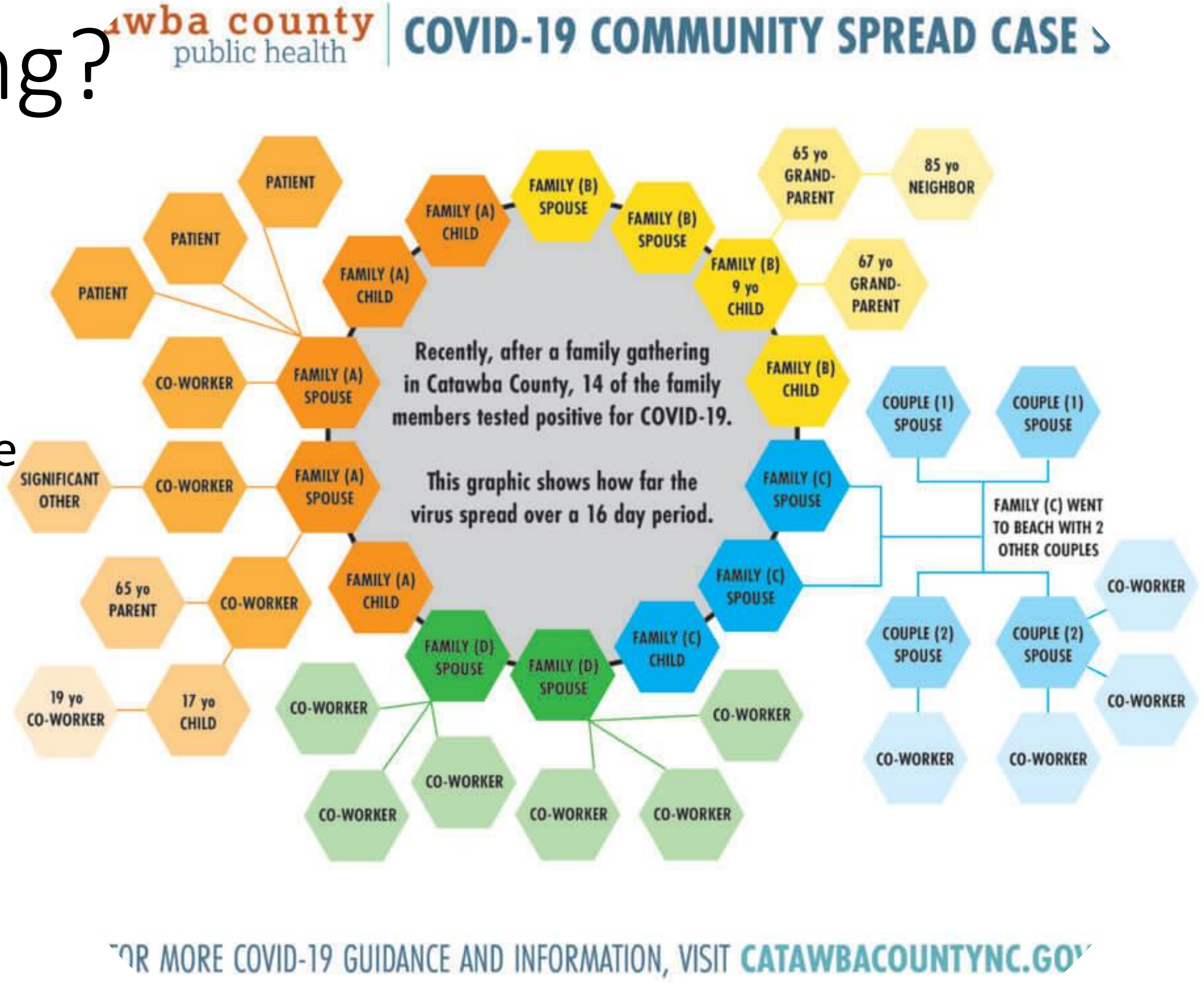
Overview


Water vapour is a useful tracer of circulation of air indoors
Bluetooth®-based contact tracing for COVID-19 is not accurate enough
Water vapour concentration can be measured surprisingly accurately and cheaply
More Accurate Contact Tracing:
Water vapour (and also pressure) measurements
+
Bluetooth®

What is contact tracing?

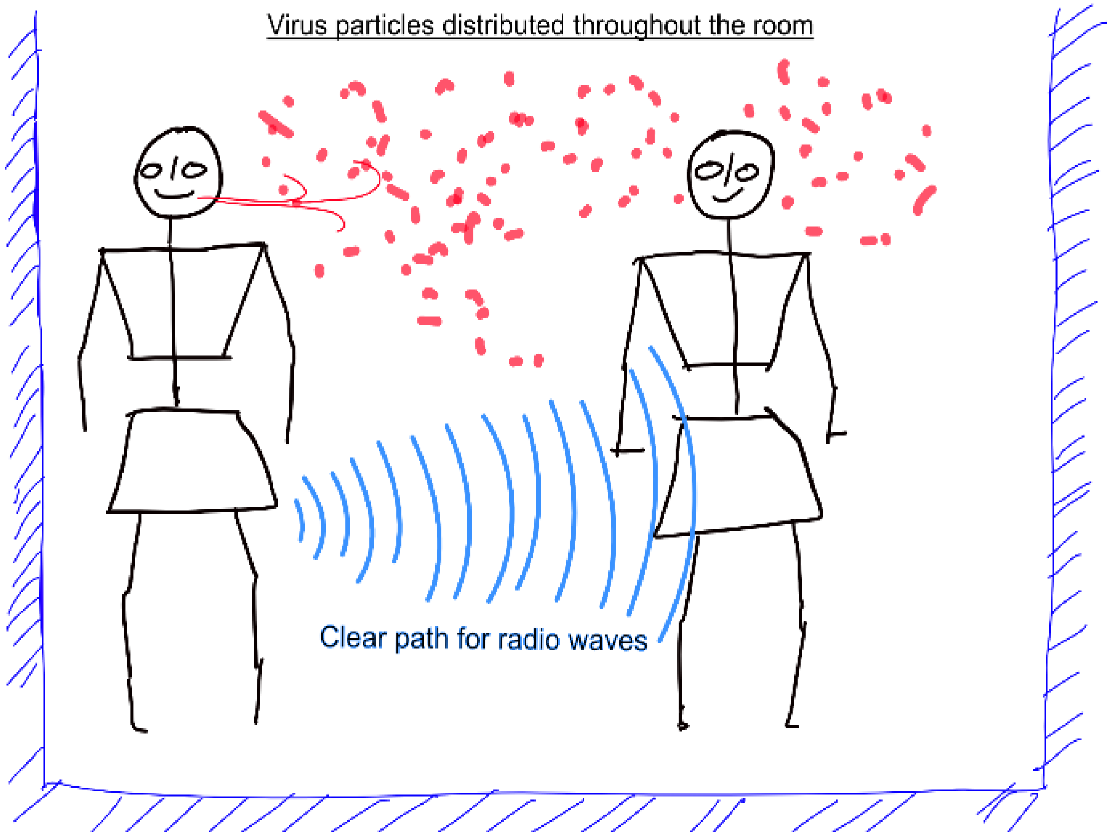
- <u>Goal</u>: Isolate infectious persons *before* they develop symptoms
- <u>Manual contact tracing:</u> obtain contact history from known infectious persons, trace all of the contacts and ask to isolate
  - Missed contacts -- *false negatives*
  - Labour intensive if prevalence is high
- <u>Technological contact tracing:</u> record electronically all potential contacts pre-emptively; when a person is confirmed infectious message all those contacts
  - *False positives*
  - (Implementation complexities)
  - (Privacy issues)

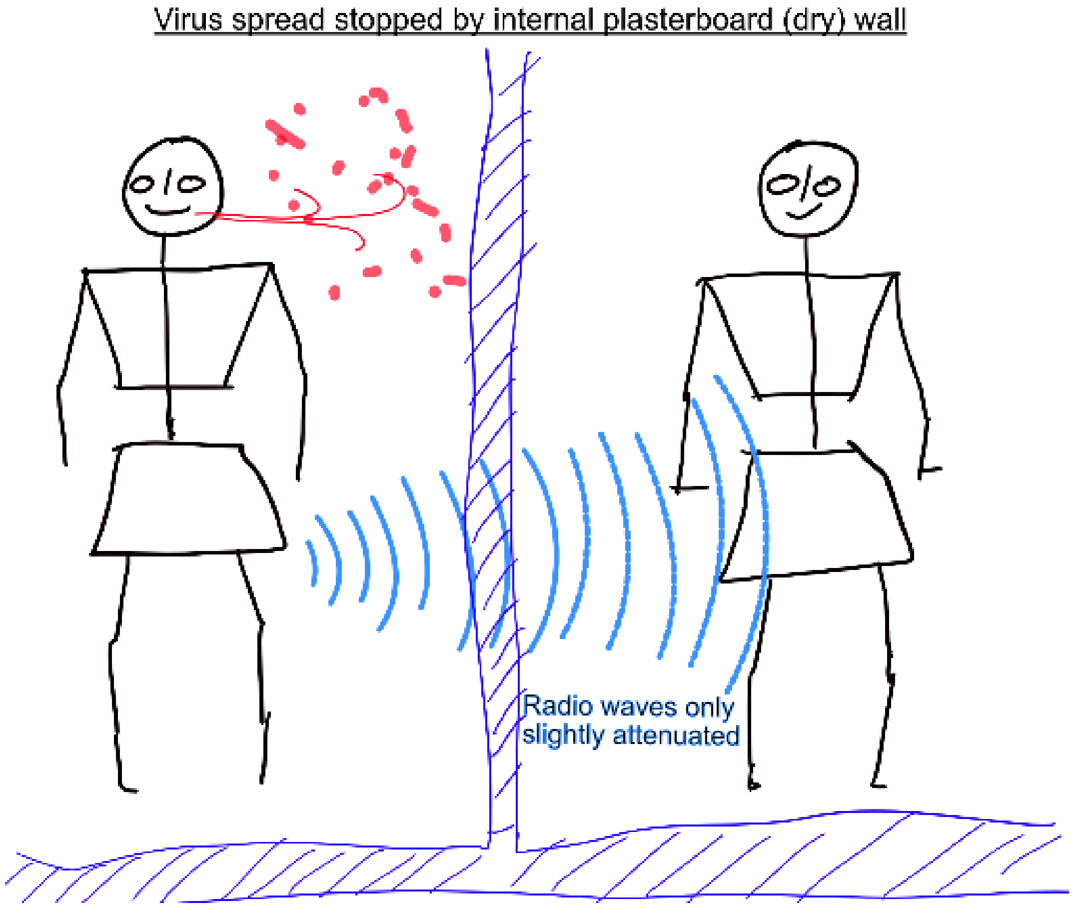


Shortcomings of the current Bluetooth®-based approach

Works by broadcasting messages at 2.4GHz / 12cm and measuring signal strength at which they are received by potential contacts

Propagation of radio waves not representative of travel of virus particles





Not easy to correct for radio wave propagation effects

- Mapping inside much less developed than outdoors
- Dependence on building techniques:
  - IR coating on windows
  - Metal vs wood studwork
  - Foil-backed insulation
- Reflections
- Effect of on-person configuration/items

Difficult to translate *strength* of a radio signal to measure of distance.

Even if it was possible, virus travels by advection hence distance alone a poor predictor

Confusion Matrix

<table>
<tr><td colspan="2"></td><td colspan="2">True condition</td><td colspan="3"></td></tr>
<tr><td></td><td>Total population</td><td>Condition positive</td><td>Condition negative</td><td>Prevalence = $\frac{\Sigma \text{ Condition positive}}{\Sigma \text{ Total population}}$</td><td colspan="2">Accuracy (ACC) = $\frac{\Sigma \text{ True positive} + \Sigma \text{ True negative}}{\Sigma \text{ Total population}}$</td></tr>
<tr><td rowspan="2">Predicted condition</td><td>Predicted condition positive</td><td>True positive</td><td>False positive,
Type I error</td><td>Positive predictive value (PPV), Precision = $\frac{\Sigma \text{ True positive}}{\Sigma \text{ Predicted condition positive}}$</td><td colspan="2">False discovery rate (FDR) = $\frac{\Sigma \text{ False positive}}{\Sigma \text{ Predicted condition positive}}$</td></tr>
<tr><td>Predicted condition negative</td><td>False negative,
Type II error</td><td>True negative</td><td>False omission rate (FOR) = $\frac{\Sigma \text{ False negative}}{\Sigma \text{ Predicted condition negative}}$</td><td colspan="2">Negative predictive value (NPV) = $\frac{\Sigma \text{ True negative}}{\Sigma \text{ Predicted condition negative}}$</td></tr>
<tr><td colspan="2" rowspan="2"></td><td>True positive rate (TPR), Recall, Sensitivity, probability of detection, Power $= \frac{\Sigma \text{ True positive}}{\Sigma \text{ Condition positive}}$</td><td>False positive rate (FPR), Fall-out, probability of false alarm $= \frac{\Sigma \text{ False positive}}{\Sigma \text{ Condition negative}}$</td><td>Positive likelihood ratio (LR+) $= \frac{\text{TPR}}{\text{FPR}}$</td><td rowspan="2">Diagnostic odds ratio (DOR) $= \frac{\text{LR+}}{\text{LR−}}$</td><td rowspan="2">$F_1$ score = $2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$</td></tr>
<tr><td>False negative rate (FNR), Miss rate $= \frac{\Sigma \text{ False negative}}{\Sigma \text{ Condition positive}}$</td><td>Specificity (SPC), Selectivity, True negative rate (TNR) $= \frac{\Sigma \text{ True negative}}{\Sigma \text{ Condition negative}}$</td><td>Negative likelihood ratio (LR−) $= \frac{\text{FNR}}{\text{TNR}}$</td></tr>
</table>

https://en.wikipedia.org/wiki/Confusion_matrix

Contact Tracing Confusion Matrix - *quiescent*

		True Infection Status		Rates	
	Total Population 67×10^6	True Infected 20×10^3	True Not Infected 67×10^6	Prevalence $\frac{1}{3000}$	
Predicted Condition	Predicted Infected	True Positive 10×10^3	False Positive Type I Error 30×10^3		False discovery rate $\frac{3}{4}$
	Predicted Not Infected	False Negative Type II Error 10×10^3	True Negative 67×10^6		
		Sensitivity $\frac{1}{2}$			
			Specificity 99.96%		

NB high apparent specificity – due to the error rate being proportional to number of infected persons

Contact Tracing Confusion Matrix - widespread

		True Infection Status		Rates	
	Total Population 67×10^6	True Infected 200×10^3	True Not Infected 67×10^6	Prevalence $\frac{1}{300}$	
Predicted Condition	Predicted Infected	True Positive 100×10^3	False Positive Type I Error 300×10^3		False discovery rate $\frac{3}{4}$
	Predicted Not Infected	False Negative Type II Error 100×10^3	True Negative 67×10^6		
		Sensitivity $\frac{1}{2}$			
			Specificity 99.6%		

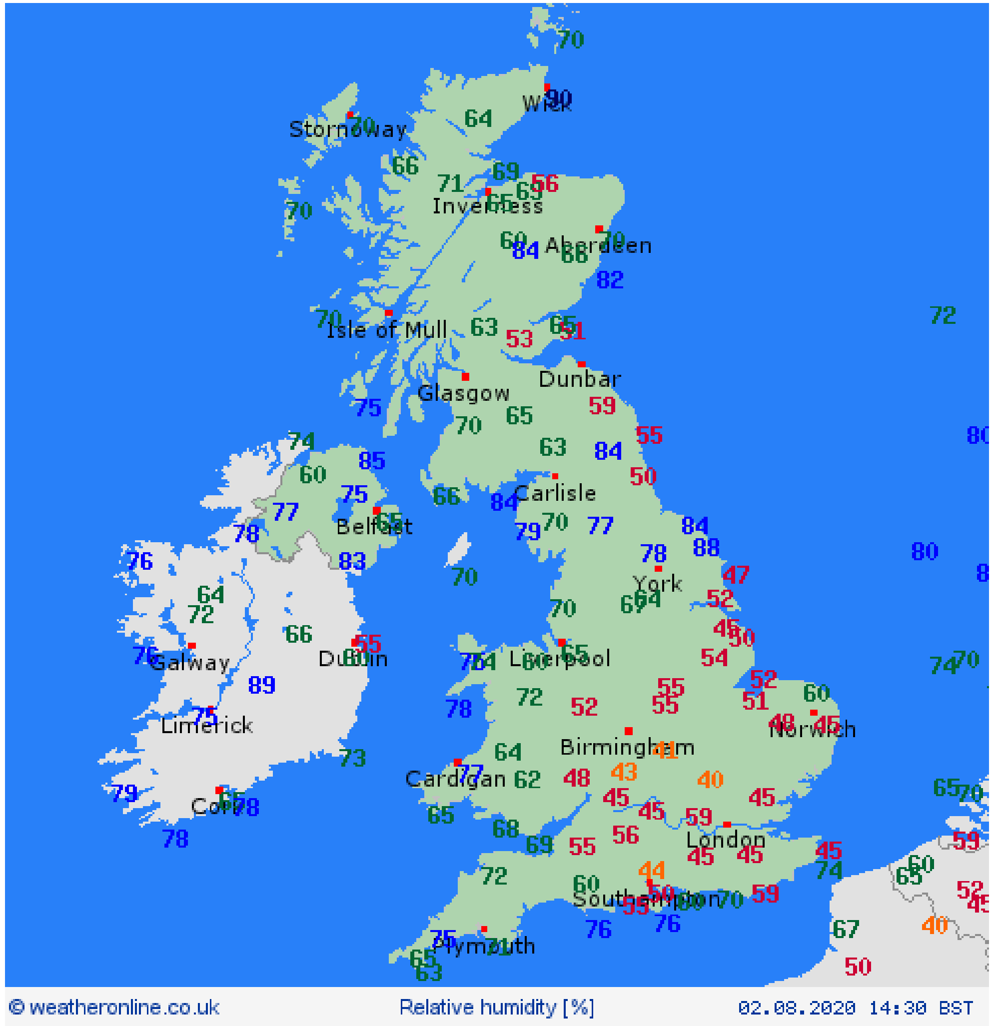
Contact tracing very difficult when virus widespread – one of the reasons for a "lock-down"

More accurate prediction of virus transmission

Introduce a second factor: measuring the mixing of air between potential contacts

Relative Humidity / Water Vapour Concentration

- Familiar from weather forecast
- Changes over long timescales (hours) and long distances (100s kilometres)



- But also has a microstructure! Happens to be the main limitation for radio telescopes operating above 75GHz

Water vapour indoors

- Exhaled human breath is saturated with water vapour
  - 100% relative humidity
  - ~6kPa partial pressure
  - One breath about one litre volume ~ one gram total mass
    - Of which ~0.04 millilitres of water
- Air layer next to skin is also high in water vapour
- Design of indoor spaces (and clothes) often revolves around efficient removal of this water vapour without excessive heat loss
- Turbulent mixing of water vapour by ventilation air flows

Historical way of measuring humidity

Hair + Spring

- Horse or human hair tensioned by a metal spring
- Extension of spring controls a needle on a dial
- Surprisingly accurate

Limitations:

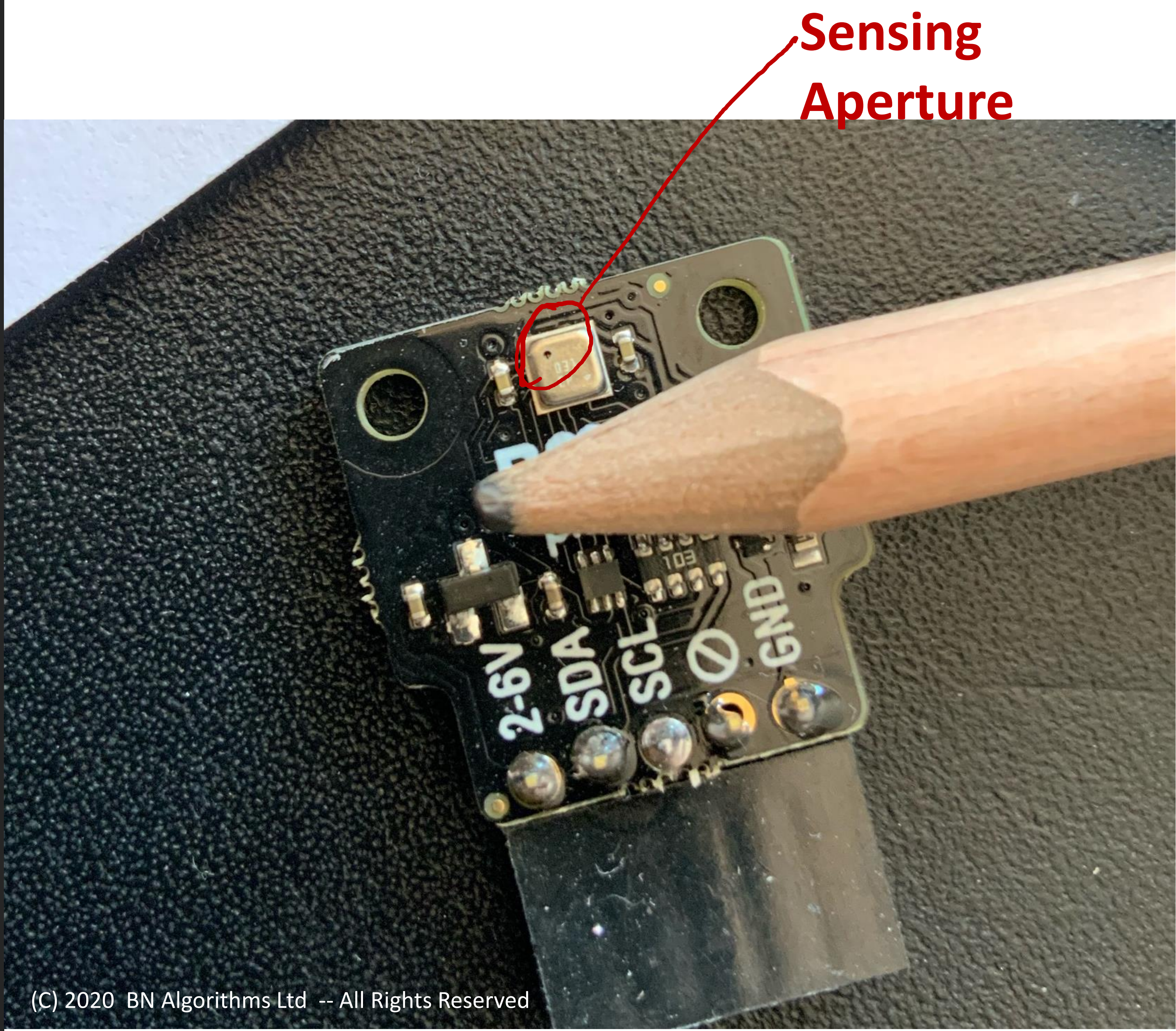
- Long time constant
- Low precision

Applications:

- Measure humidity averaged over long time in a room
- Long time average -> Space average

https://commons.wikimedia.org/wiki/File:Haar-Hygrometer.jpg

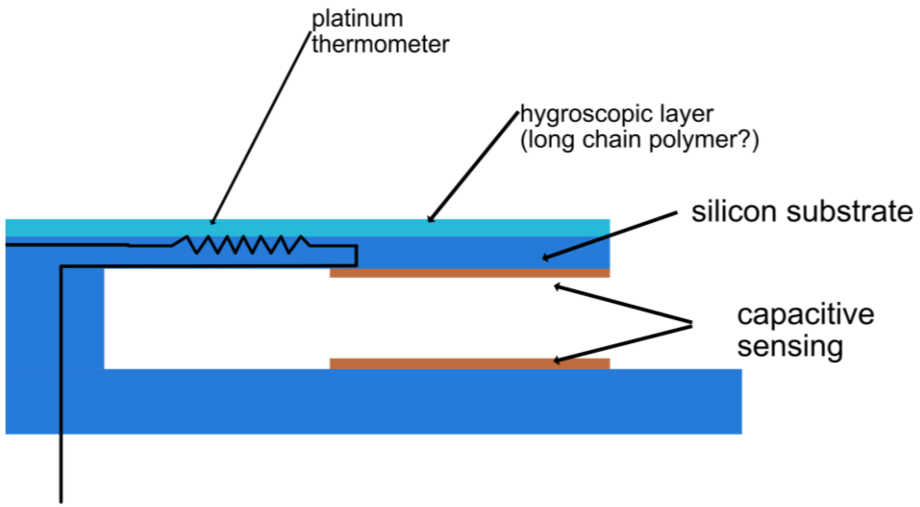
Miniaturised Humidity Pressure Temperature (+ heated catalytic converter with charge detector) Sensor

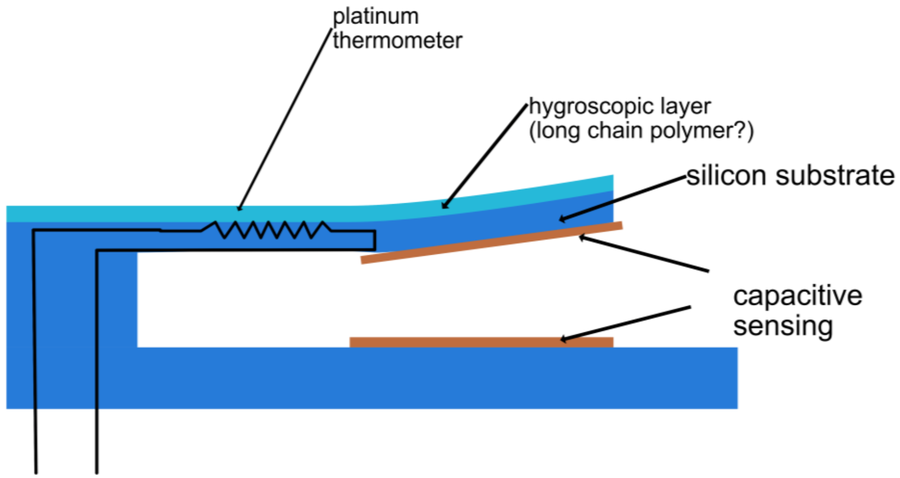


MEMS Cantilever Hygrometer

- Reasonable absolute accuracy which is limited by hysteresis
- Likely same physics as old-fashioned human/horse hair spring hygrometers
- Capacitive sensing provides very high readout precision (?phase shift versus uncoated identical structure?)

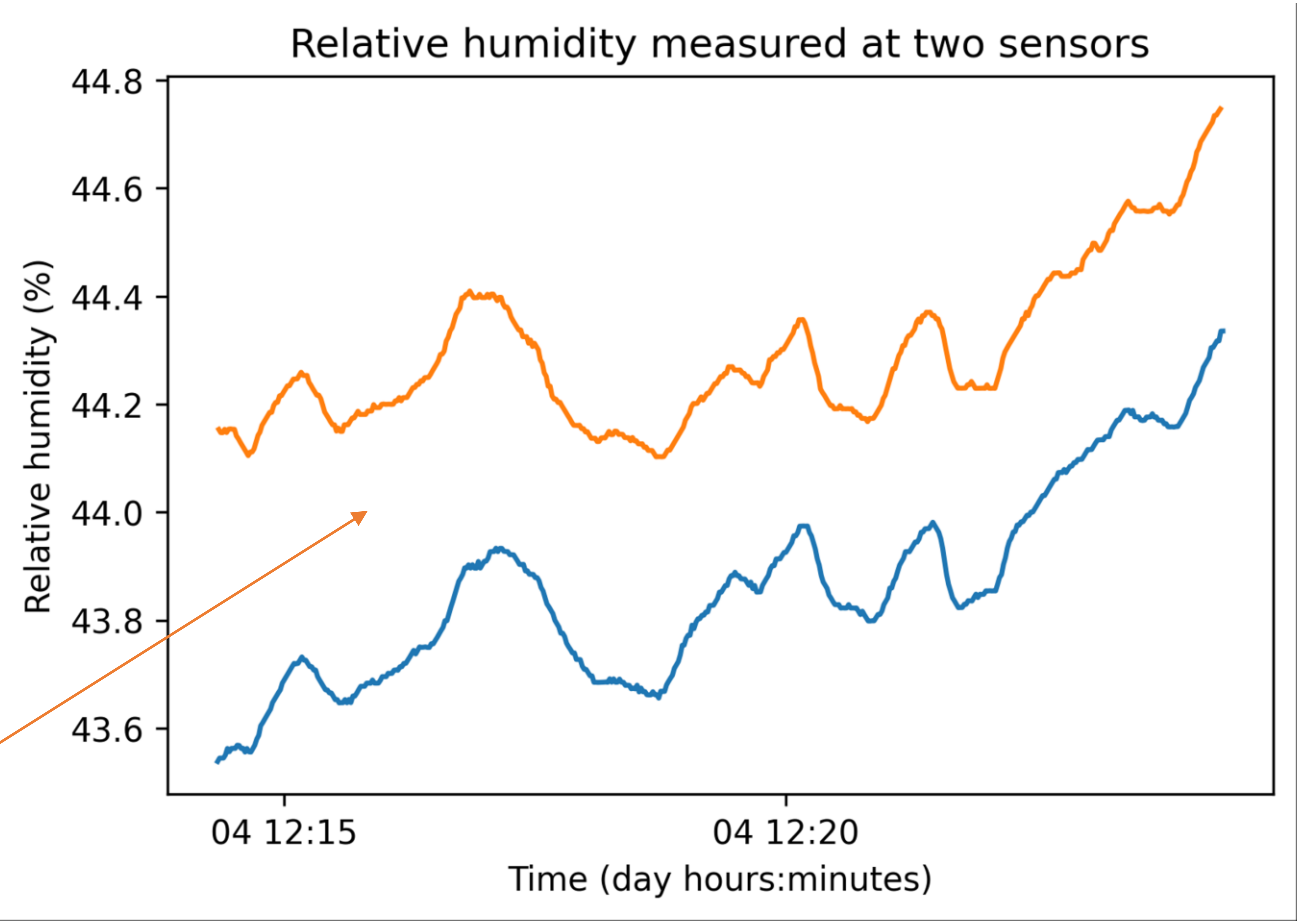
- Dew-pointe MEMS hygrometers have also been developed. Seems unlikely they are needed in this type of application.





Quiescent Relative Humidity Fluctuations Indoors

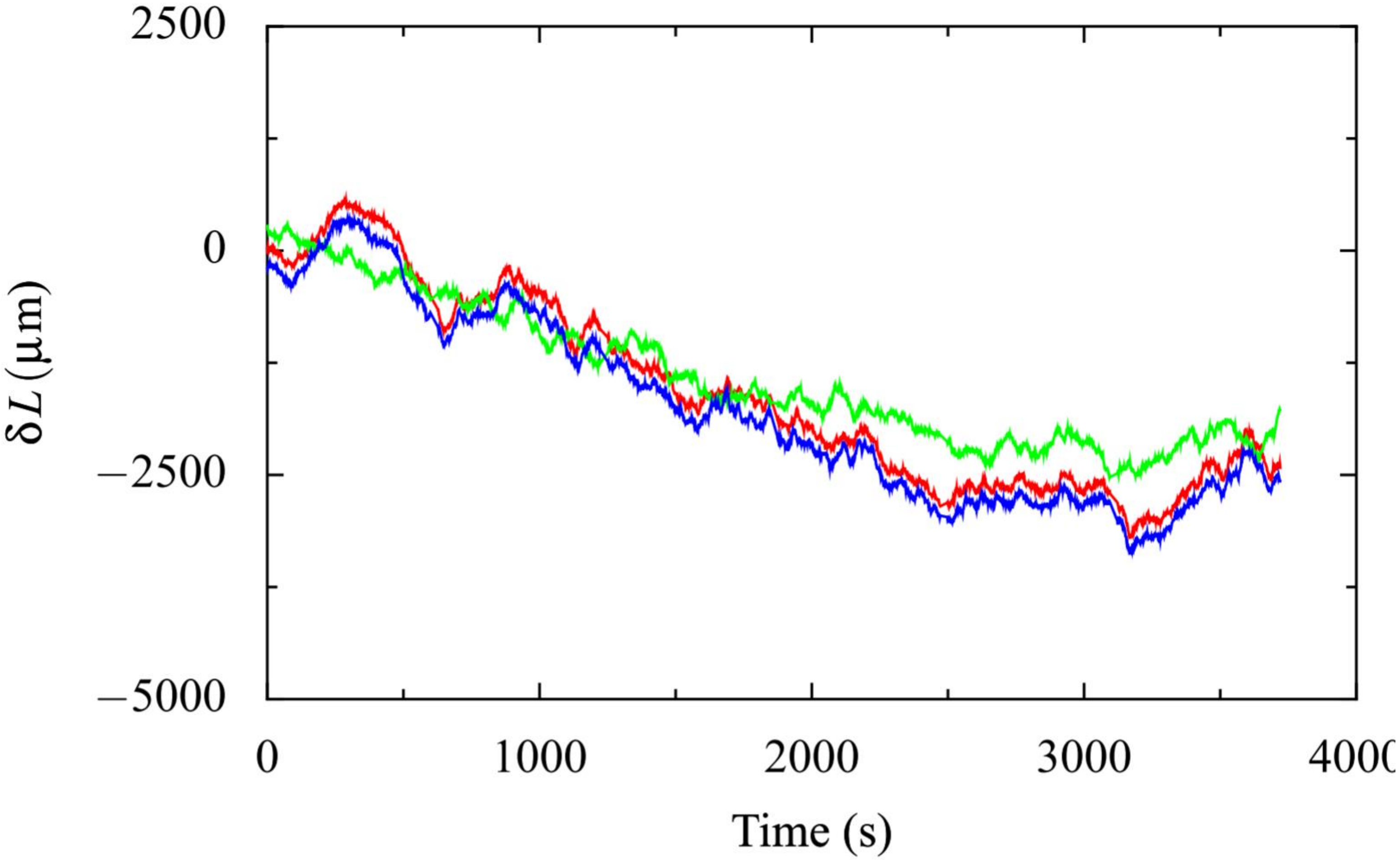
Two sensors, side by side on (home) office desk. Typical environment (one person, windows slightly open).



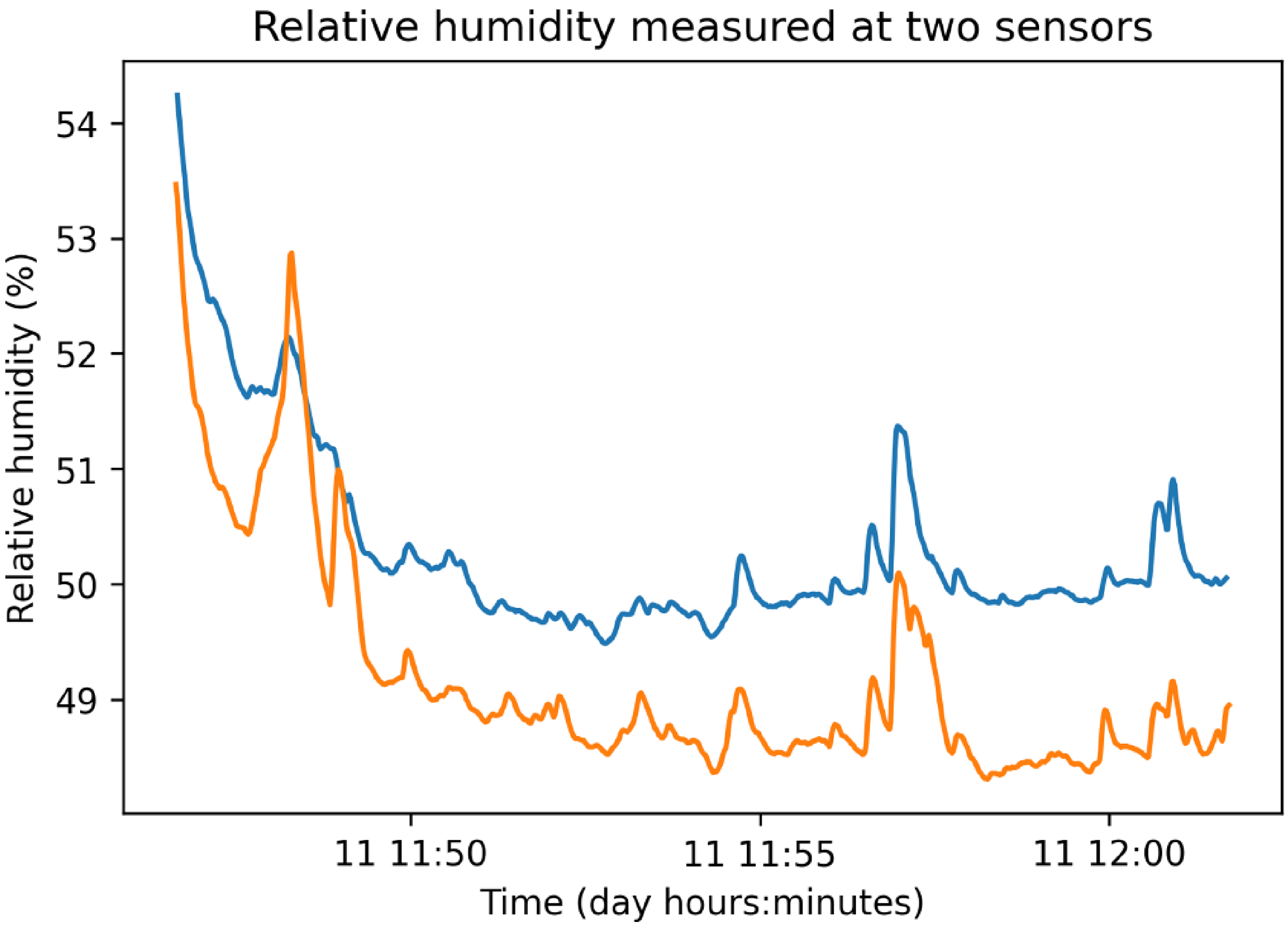
Close correspondence of fluctuations – basis of operation of improved contact tracing

Fluctuation of line-of-sight integrated water vapour at ALMA

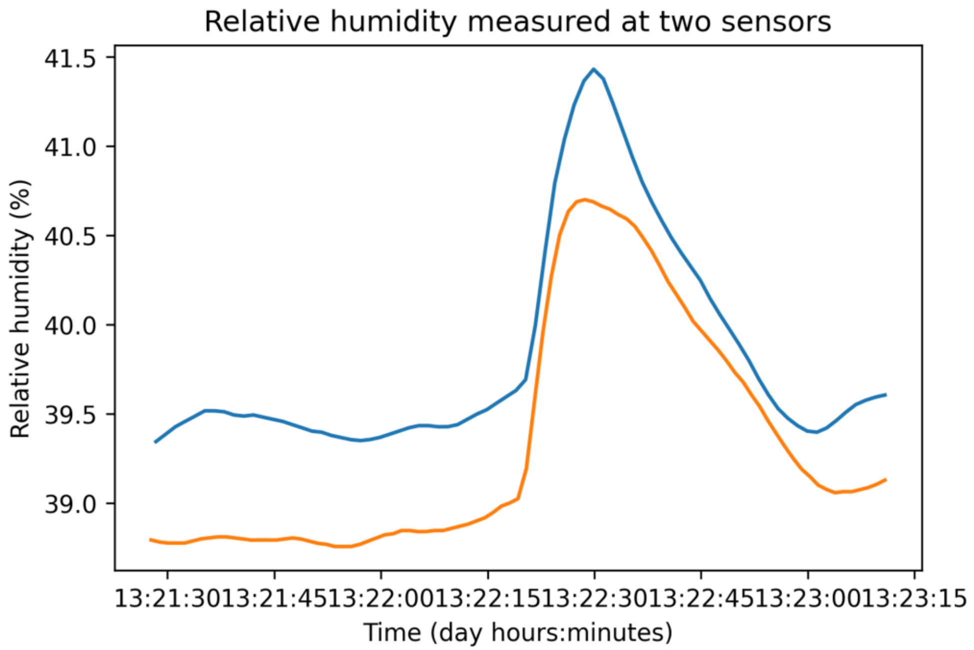
This data probably ~2mm PWV, so about 15mm path. The fluctuation is therefore about 15% peak-to-peak.

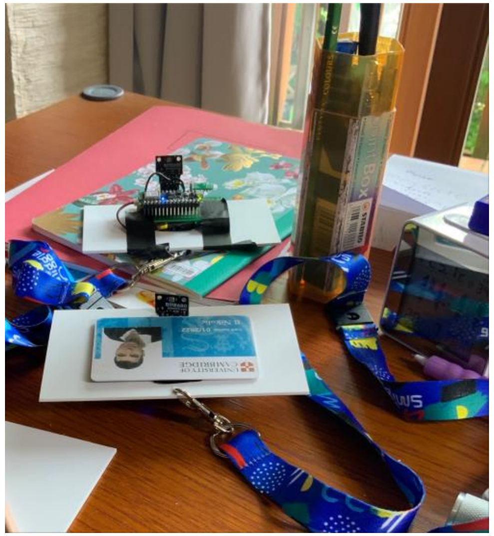


Two sensors worn together



Blowing a single breath toward the sensors

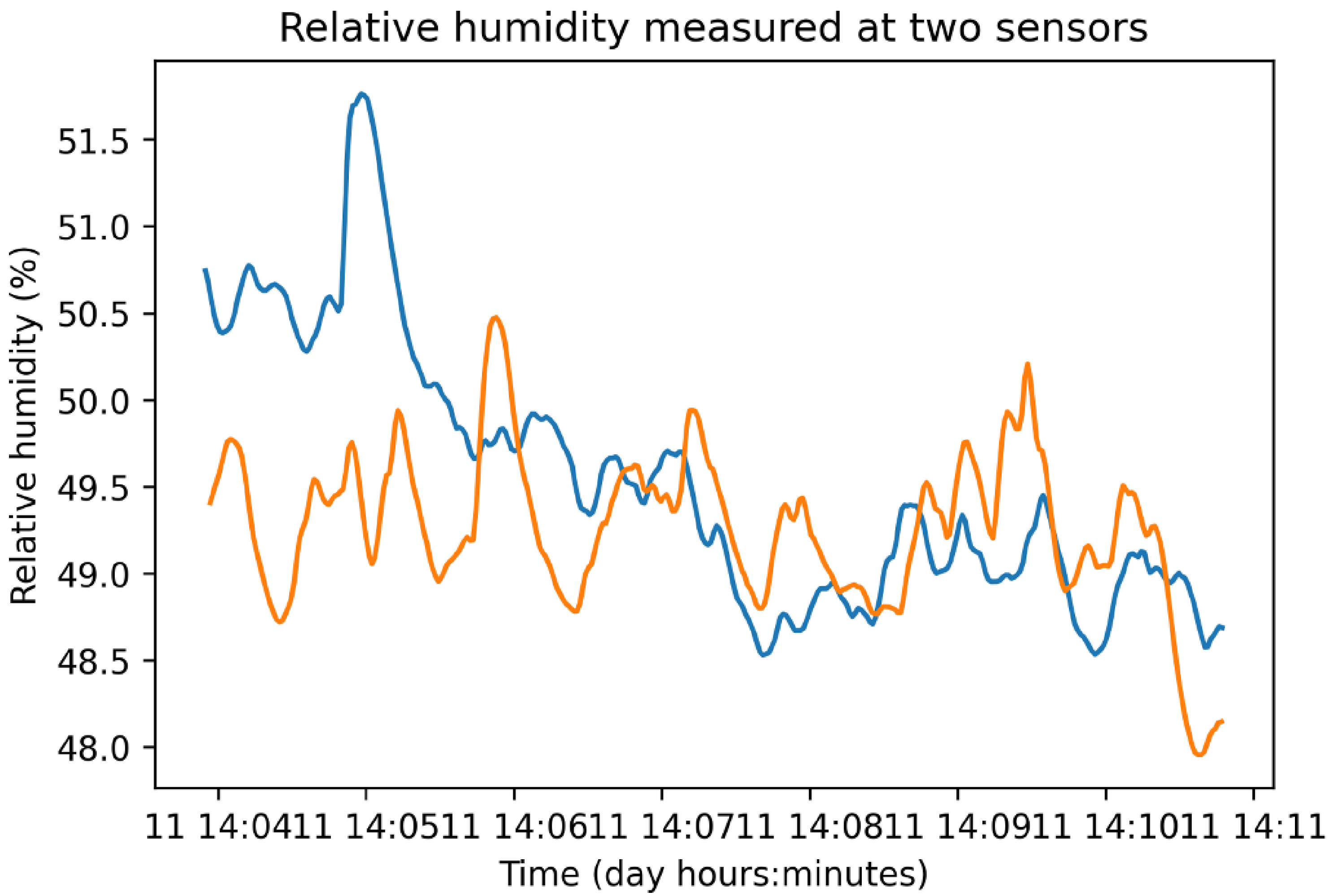




- Single (moderately hard, perhaps like singing or talking loudly) breath easily resolved
- Shows ~10second time constant and asymmetric response to rising vs falling humidity
- Nearest sensor was about 70cm away

Two persons in conversation

- About 1 metre apart.
- In an office-like environment
- 7 minutes recording
- Both wearing prototype sensors built into a ID badge holder



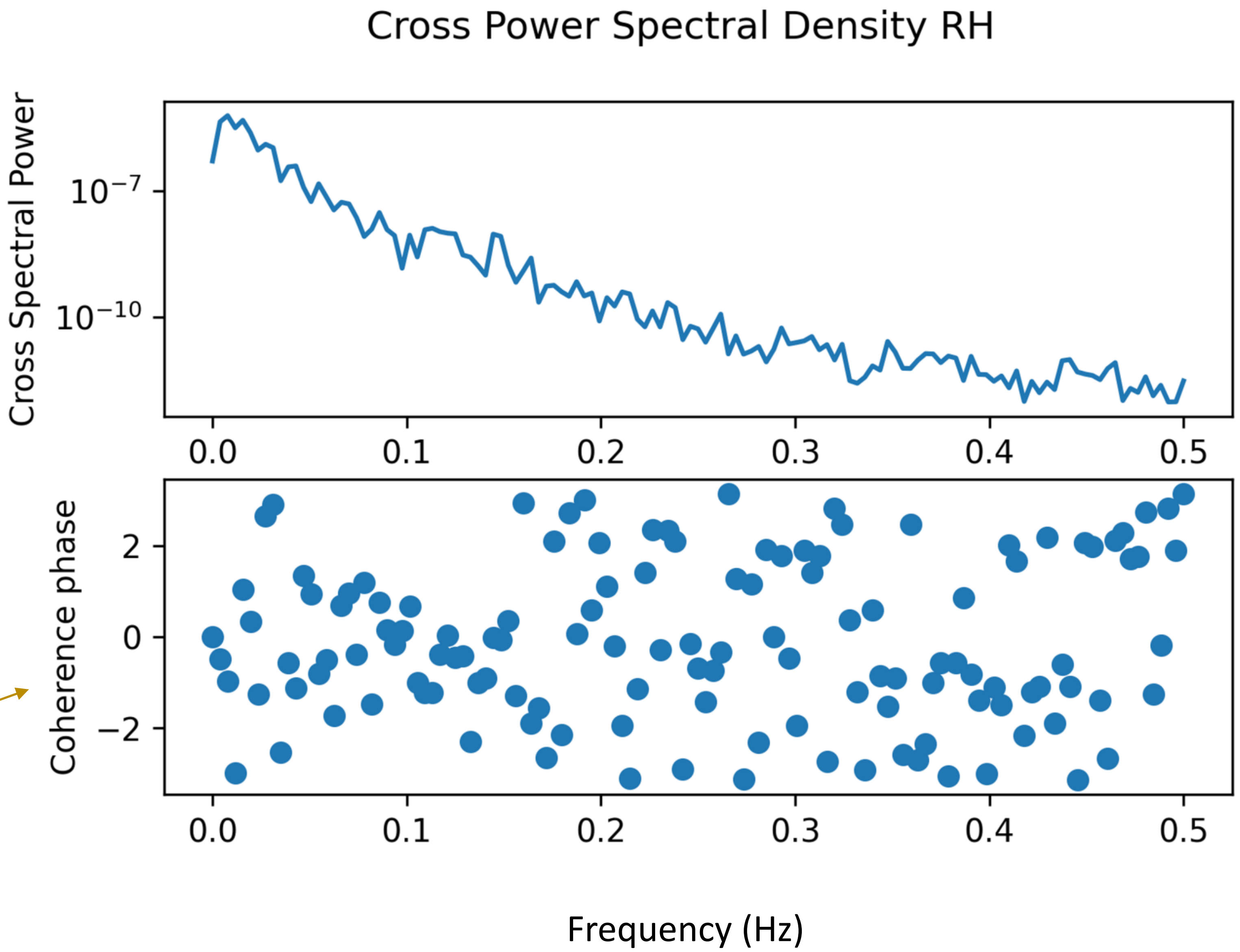
Contact or not contact?

Identify correlation using the cross-spectral power density

Potential for higher order signature?

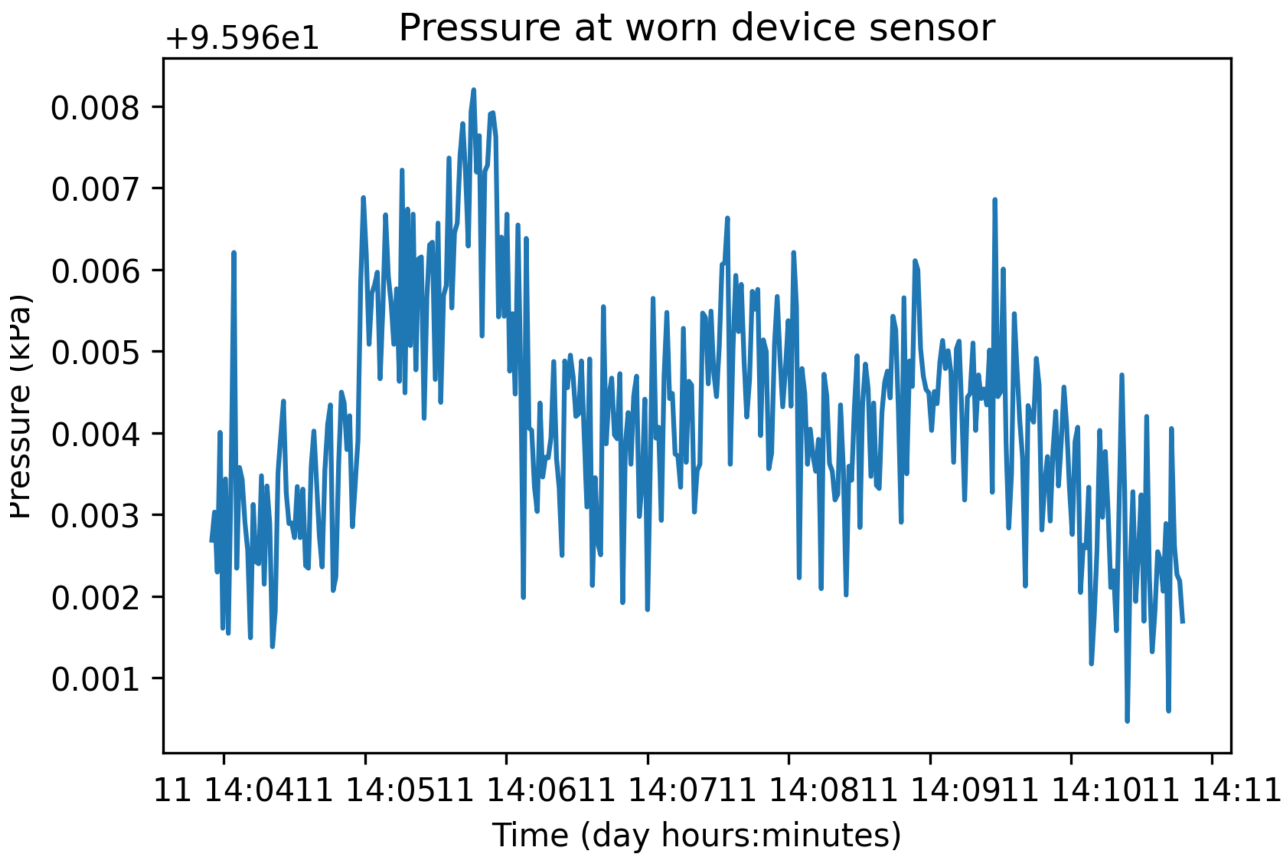
This is also how radio telescopes work!

I've spent many nights in the Atacama desert looking at plots like this.



Pressure as an additional variable

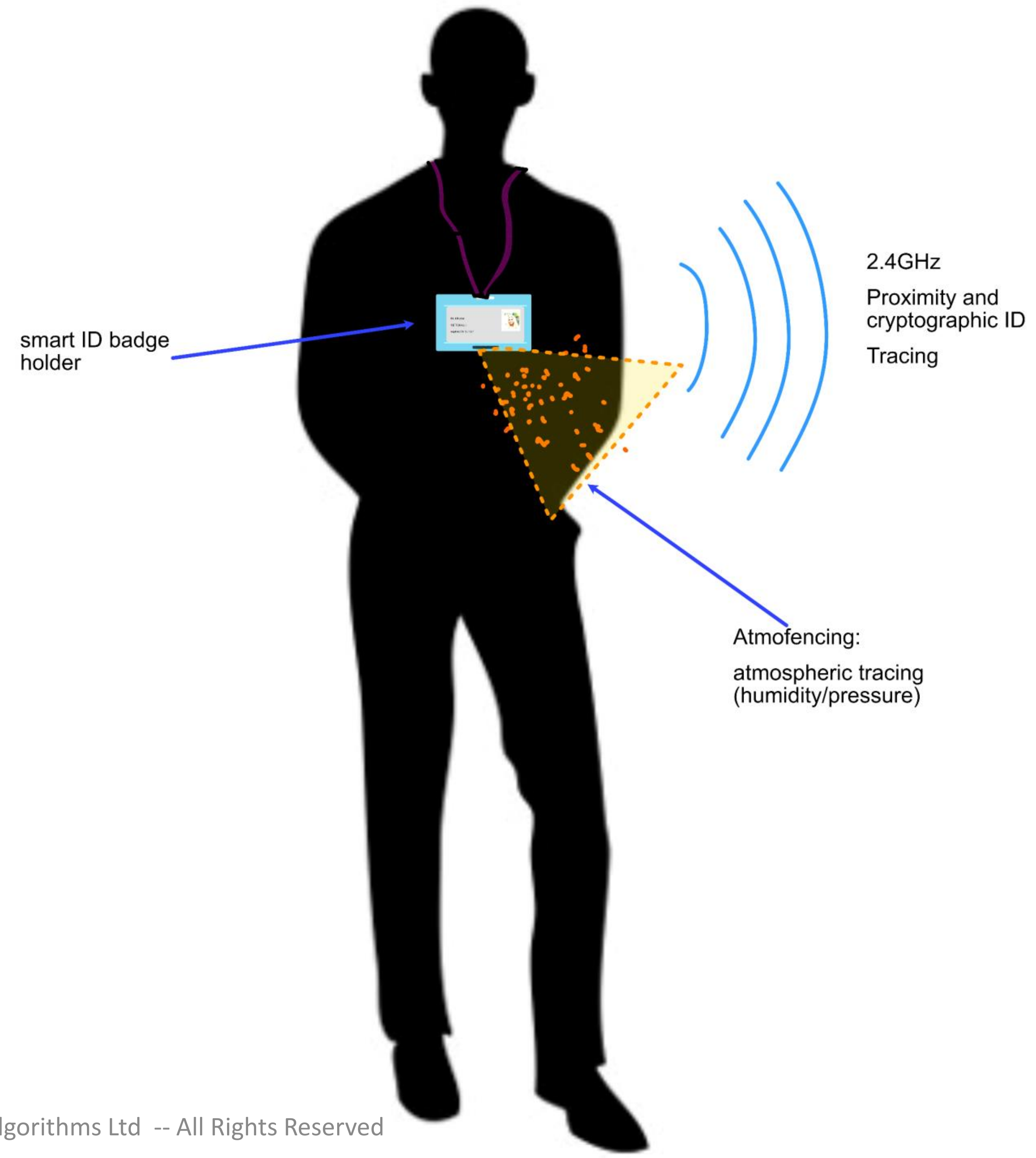
1. Easily sensitive enough for all relevant height differences (1m~10 Pa, whole range on plot to right)
2. Useful dynamics in closed spaces (doors opening, closing, changes in ventilation)



Implementation concept and prototype

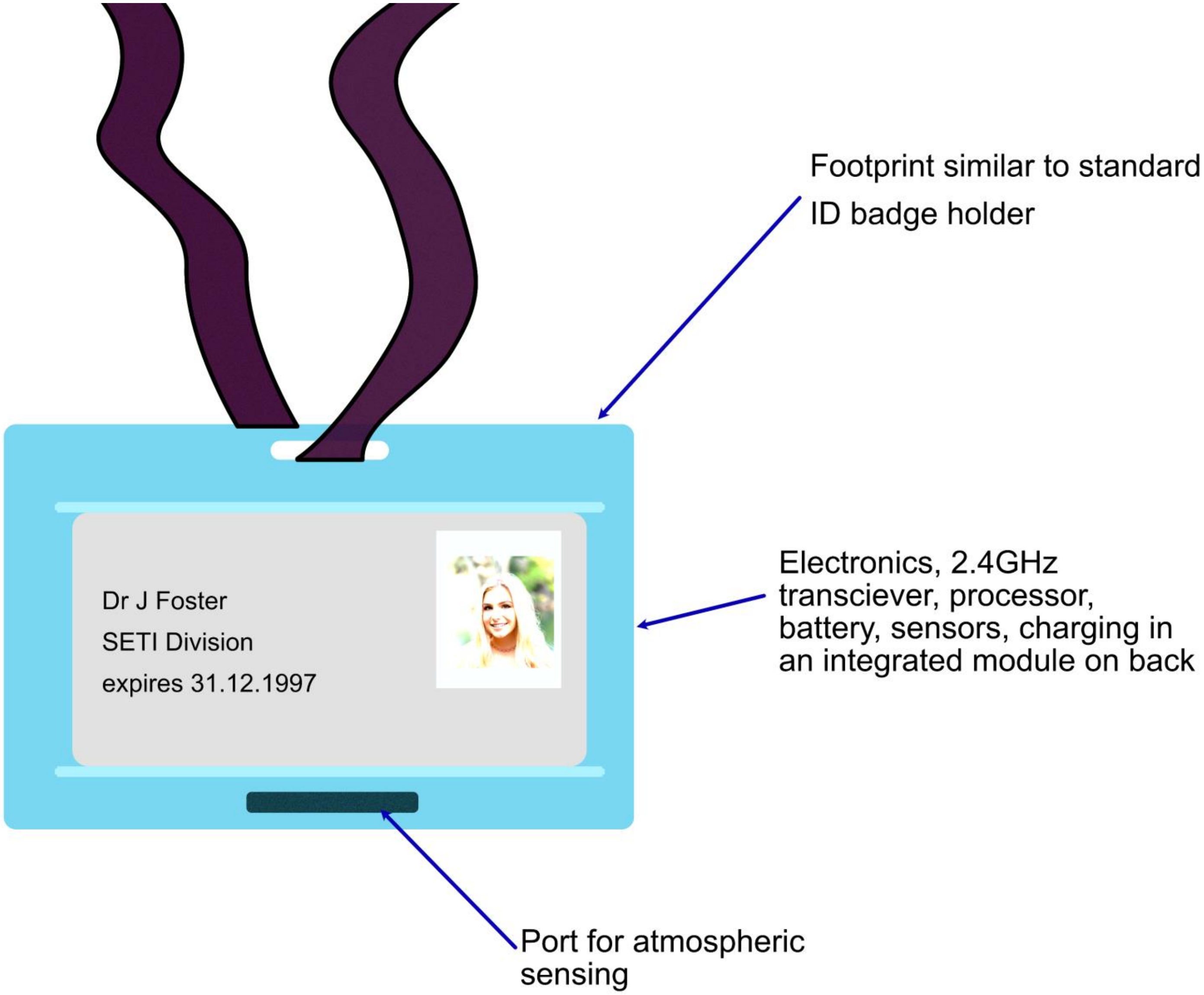
A "smart" ID badge holder

- Optimal position
- Many people already used to wearing one



Device Concept

- Total weight of electronics, sensors, battery < 40g
- Whole day battery life very easily achievable

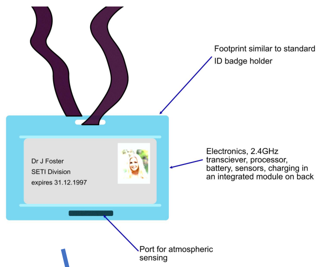


Prototype

- Off the-shelf micro-controller, Bluetooth module, atmospheric sensing, battery & power conditioning.
- Low power (~1mA), low weight (prototyping elements more then electronics and battery).

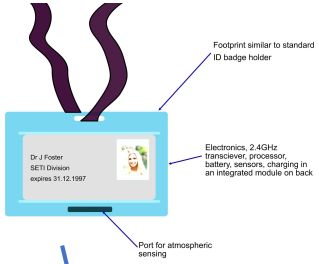
Data collection and processing concepts

Augmented Contact Tracing for high-risk situations (hospitals, education, care homes) but maximum integration with existing IT infrastructure



Bluetooth

Internet



Bluetooth

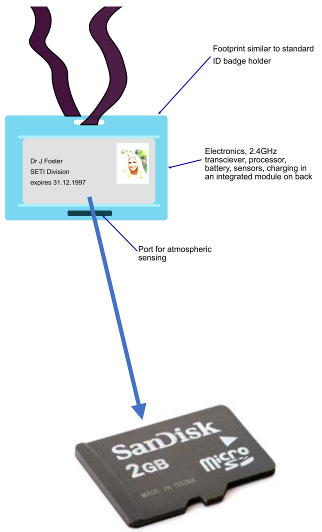
Internet

Existing contact tracing infrastructures based on mobile phones

Data collection and processing concepts

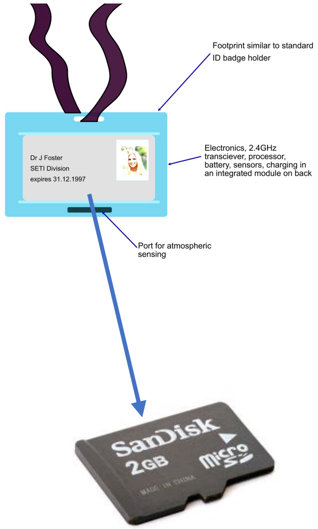
Maximum Privacy:
Local data processing only in case of confirmed case in organisation

Cryptographic anonymisation
Only confirmed positives publish information.
No data leaves badge with user input



Only on user trigger

Private Servers



Only on user trigger

Summary

Summary

- MEMS sensors open new possibilities in tracing how air mixes indoors
- Practical & low cost way of improving contact tracing for COVID-19
- Incentive to deploy greatest if/where virus prevalence is high
- Potential settings:
  - Hospitals
  - Dense office buildings
  - Education settings (especially higher?)
  - Care Homes
- More information: www.atmofencing.com