How far can we push our understanding of animal behaviour, ‘opinion’ and ‘state’ with sensors?

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This all depends on the sensors;

Animal-dependent

Accelerometers

Magnetometers

Pressure

Environment-dependent

Temperature

Light
Animal-dependent

Tri-axial-accelerometers

Tri-axial-magnetometers

Pressure

“The whole is greater than the sum of its parts”
Tri-axial-accelerometers provide a proxy (DBA) for animal speed.

Fig. 1. Linear regressions for ODBA against speed for the 8 species trialled at Buenos Aires Zoo during treadmill exercise.
Tri-axial-accelerometers together with tri-axial-magnetometers provide heading;

The rotation matrices (modified from [34]) for pitch and roll, given as $R_y(\beta)$ and $R_x(\gamma)$ respectively are expressed by;

$$R_x(\gamma) = \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos \gamma & -\sin \gamma \\
0 & \sin \gamma & \cos \gamma \\
\end{bmatrix}$$

$$R_y(\beta) = \begin{bmatrix}
\cos \beta & 0 & \sin \beta \\
0 & 1 & 0 \\
-\sin \beta & 0 & \cos \beta \\
\end{bmatrix}$$

Derivation of heading
The heading ($H$) in degrees may be calculated simply (see [84]) via;

$$H = (\text{atan2}(RNm_y, -RNm_x)) \cdot \frac{180}{\pi}$$
Speed and heading and change in height allows the movement of a tag-equipped animal to be dead-reckoned!
To stop system errors, periodic ground truths are required!

**Fig. 10** The movements of a rider-directed horse Equus ferus caballus, starting and ending in the top left corner, as elucidated by GPS (at 1 Hz - *black track*) and dead-reckoning (at 20 Hz) without any ground-truthed points (*red track*). Note that the dead-reckoned trace has no scale since the distance moved is derived from the speed and this is assumed to be linearly related to VeDBA, with a nominal relationship until ground-truthed (see text). The two dashed squares show a period when the horse was directed to move in tight circles. For scale, the total track length according to the GPS (*black track*) was 10.127 km.
The resolution of dead-reckoned data is unprecedented and shows behaviours as variability in the trajectory manifestation.

**Fig. 11** Movement path of a domestic dog. The purple track displays the GPS data (at 0.2 Hz) while the green shows the dead-reckoned path (at 40 Hz). For scale, the total track length according to the GPS was 3.040 km. Note the additional track tortuosity of the dead-reckoned track.
This system also applies in 3D

Fig. 3 Dead-reckoned track of a European badger (Meles meles) in Northern Ireland leaving its sleeping quarters (red dashed circle) and moving through the underground sett to emerge at the entrance (yellow circle). The vertical axis representing depth is shown as the pressure difference between the surface and any time underground. The reconstruction assumes that animal speed is directly proportional to VeDBA [4] underground in the same way it is on the surface. If this is not the case, the derived distances will be affected accordingly.
Behaviour – Tri-axial sensors and the importance of directionality - Magnetic North and Gravity -
Behaviour – Magnetometers give a signal output that is proportional to their angle to the magnetic field

Field lines are horizontal at the magnetic equator and vertical at the magnetic poles.
Tri-axial should be plotted in three axes

Different behaviours show different patterns on an ‘m-sphere’
Patterns summed over time show the importance of directionality

Orientation is much more important than we think
Tri-axial accelerometer data are terrifying

There are multiple ways of dealing with them
But 40 Hz, 3 acceleration channels – Data narcosis and interpretation

5 hours of animal data
5 seconds
What should we do when it all gets too much?
One way to examine data is to use models.
The glasses you wear will change the way you think.
One of the ways to highlight patterns
Tri-axial accelerometers

Same principle as magnetometers but accelerometers are insensitive to heading because the gravitational field goes directly down.
Tri-axial should be plotted in three axes

Shows pitch and roll (attitude) well
Spherical plot advantages
If we plot a tri-axial graph without considering that forces recorded are due both to gravity and those derived from the animal.
The ‘bounce’ in the signal comes from the animal (and actually is a powerful proxy for energy expenditure)

'Bounce' – derived from accelerometer data

*Fig. 1. Best fit linear relationships between rate of oxygen consumption and ODBA for a range of bipedal and quadrupedal species while resting and walking/running on a treadmill. Other behaviours were also displayed. Where data are available for multiple individuals of a species, a common slope is shown, derived from a linear mixed effects model. For clarity, the running order of species on the legend follows the order of slopes on the graph from top to bottom. Data for humans are included in an inset figure because values for rate of oxygen consumption are an order of magnitude greater than that of the other species.*
We can normalise tri-axial plots these to illustrate postural changes (and colour code them according to ‘bounce’ [energy expenditure])
But since larger data sets obscure data
We can sum data points within facets [1280 shown here]
And provide histogram plots to deal with this [1280 facets]
Plot with enhanced resolution [20480 facets]

Modes = behaviours

But we have lost the energy expenditure information
Take each mode
Repeat the process for all facets, helping describe behaviour
This gives us multiple parameters to help separate behaviour.

How far can we push this sort of thing?
Because our body moves in particular ways according to state!
‘Emotional’ state
Before fall

After fall

‘Before’ minus ‘after’
'Happy/sad' elephants!
Disease state!
Chemical state!
After identification of behaviour, state etc – fusing with derivatives with finely resolved movement and space use trajectories

Fig. 7 Dead-reckoned trajectory of a cow with overlaid behaviour - The dead-reckoned trajectory of a cow (Bos taurus) in a field in Northern Ireland over 2 h, colour-coded according to different activities – green = grazing, black = walking, red = lying down
Adding loggers e.g. system deployment on heads for feeding/orientation behaviour (colour codes for head pitch)!
Consumption!

- Northern Irish Sheep
- Argentinean Sheep
So where are we now with all this?
New approaches are turning things on their head
Truly exciting times!!!