The vibratory world of termites

Ra Inta,
The Centre for Gravitational Physics,
ANU
Assumptions

Linearise Einstein field equations:

\[ G^{\mu\nu} = \frac{8\pi G}{c^4} T^{\mu\nu} \]

By imposing constraints on metric tensor:

\[ g^{\mu\nu} = \eta^{\mu\nu} + h^{\mu\nu} \]

where \( h^{\mu\nu} \) is a small perturbation (\( |h^{\mu\nu}| \ll 1 \)) about Minkowski (flat) metric \( \eta^{\mu\nu} \)
Termite perturbation tensor

Assume undulatory form for $h^{\mu\nu}$

However, because termites are very little insects, their perturbation tensor has to be written very very small also:

$$h^{\mu\nu}_{\text{termite}} \rightarrow h^{\mu\nu}_{\text{termite}}$$
The vibratory world of termites

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Antennae

1. Justification/background
2. Vibration as an information source
3. Vibration as a survival aide
4. Vibration as a communication channel
5. Applications: exploiting termites’ vibrations
1: Justification: why termites?
Termites are evil!

- High cost: A$ 800M per year, US$5-10 G worldwide
- Complex, successful societies---more so than humans (biomass, anyway)
Vibrations: mounding evidence

It has been known for more than 2,000 years that termites use vibrations in communication: Their name is derived from the Greek ‘Termes’, meaning ‘the end’.

Henry Smeathman reports to the Royal Society (1781)
Biological clues

- (Eu)social, complex societies
- Blind
- Limited pheremonal repertoire
- Simple ($10^5$ nerve cells in cerebral ganglia)
- Pathetic
- Over 80% of arthropod species use vibration
- Sensitive mechanoreceptors in termites
- Observed responses to vibrations
Threshold of subgenual organ: $\theta \sim 0.2$ nm

S.R. Shaw: “Re-evaluation of the absolute threshold and response mode of the most sensitive known vibration detector, the cockroach’s subgenual organ: A cochlea-like displacement threshold and a direct response to sound,” *Journal of Neurobiology, 25*(9), pp. 1167-1185 (1994)
Termites use vibrations to gather information about food sources, competitive species and other potential dangers.

- **Background**
- **Characteristics of feeding and mechanical signals and material properties**
- **Bioassay experiments**
Assessment of food structures

Classic experiment (opposite blocks) a result/extension of Lenz


Somehow, termites know the extent of their food resources and make reproductive decisions based on this.

How do they know?
Control of substrate
Measurement of foraging signals

- Foraging termites (inside wood)
- Wood (Pinus radiata)
- Clamp
- Accelerometer (B&K4370)
- Charge amplifier (B&K2635)
- Computer and soundcard
Spectrogram of termites feeding on 320mm wood block (Copt. lacteus)
Beam mechanics

Food substrate acts like a free-free beam

Animation courtesy of Dr Dan Russell, Kettering University
Dominant signal is of the substrate
Bioassays

• Opposite blocks, choice experiments
• Species: *Cryptotermes domesticus* and *Cr. secundus*
• Fourteen days at 30 deg. C, 80% R.H.
• Preference measures: Tunnelling activity, movement
• Have to interpret results using statistics
Cryptotermes secundus

Good test termite because:
- Can seal them into blocks of wood
- Prefer larger blocks
Signal playback
Termites assess wood size using vibration signals


Playback experiments positively show *Cr. domesticus* use vibrations, preferring *smaller* blocks of wood
What are they responding to in the signal?

Assumption: simple animal → simple feature of vibratory signal

Not clear that they respond to substrate only or convolved with voiceprint

For simple geometry, and material, the key measure could be either:

i. Frequency ($f_0$)

ii. Amplitude of acceleration ($|a| = |F|/m$)

iii. Damping (Q)?

iv. Time of flight ($\Delta t$)?
Material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Speed of sound, $c$ (m s$^{-1}$)</th>
<th>Density, $\rho$ (kg m$^{-3}$)</th>
<th>Damping factor, $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>5040±103</td>
<td>2700±28</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td><em>Pinus radiata</em></td>
<td>4930±100</td>
<td>420±30</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>EPDM rubber</td>
<td>45±1</td>
<td>504±30</td>
<td>$10^{-1}$</td>
</tr>
</tbody>
</table>
Results: tunnelling
Results: movement

Al freq.  Rubber freq.  Al mass  Rubber mass
Summary:
Termites always preferred the blocks with the most amount of wood, implying a very high level of sophistication (i.e. not a single simple measure i-iv)
Termites gain information about wood size using vibration signals

- Playback experiments---therefore vibrations
- Specific vibrations: their own species foraging (unaffected by pink noise, deterred by other species)


They can also distinguish material properties

• Not clear that they respond to substrate only or voiceprint
• Simple geometry; key measure could be $f_0$, $a = F/m$, $Q$ or $Z$

Rapidity of response

• Able to assess and make decisions relatively quickly
• Good correlation between tunnelling and movement in first five days
• Significant results in running on vibratory ‘mazes’

‘T-maze’ set-up

Diagram (a) shows the ‘T-maze’ set-up with various components labeled:
- Bulldog clip with signal
- Bulldog clip no signal
- Decision point
- Plastic cover
- Termite release point
- Cardboard T maze

Diagram (b) shows the frequency response with points labeled:
- 1
- 2
- 3
- 4
- 5
- 6
- 7

Frequency (Hz) is plotted against Amplitude (dB re 1m$^{-2}$).
a

'Indecisive'

Number

**

***

ns

6

0

6

12

‘Decisive’

b

Number

ns

12

6

0

6

12

1 (none) 2 (P→) 3 (160→)

Treatment
Conclusion: how do termites gain information about food structures?

• Not known exactly, but is vibratory in nature and highly sophisticated
• Cannot be only: \( f_0 \)
• Cannot be only: total mass
• Could be: \( Q \)
• Could be: \( Z \)
3: Vibration as a survival aide

- Invasive strategies
- Detection of other termite species
Invasive strategies

*Crypt. domesticus* (native, non-invasive): prefers *smaller* blocks of wood

*Crypt. secundus* (introduced, highly invasive): prefers *larger* blocks of wood

...highly invasive termite species prefer *smaller* blocks of wood!
Distinguishing friend from foe
Test *Cryptotermes* in central chamber

(a) Identical wooden blocks
    Vibration isolative foam

(b) Signal termites in side chamber

(c) Vibration generator
    CD player
Results

Proportion tunnel length

Control  Live  Rec’d  Coptotermes

Live  Rec’d  Coptotermes

Cryptotermes

0  20  40  60  80  100
Termites can distinguish their own vibrations from those of competitors

Termites are highly social, so have to communicate

Two main uses of vibratory signals in communication:
1. Feeding
2. Alarm

*Cryptotermes* experiments (feeding)
Attracted to similar species, deterred by competitive species
Most obvious signals: vibratory alarm

• Alarm signals produced by soldiers when they perceive a danger to the colony (mechanical breach, vibration, toxic fungal spores)
• Universal response from workers: Flee!
Signal encoding

Type of encoding in signal (spectral vs. temporal)
*e.g.* tonal language (Cantonese, Thai) vs. Morse code

Alarm signals probably independent of carrier frequency---not always very well understood in the literature
5: Applications: exploiting termites’ vibrations
Non-chemical termite control

Next generation

• Signal synthesis: don’t know temporo-spectral features termites respond to
• ‘Passive sonar’ mode: DSP triggering
• ‘Active ‘sonar’ mode: elicit behaviour
6: Future work

• Separate substrate from voiceprint of vibratory signals---signal processing
• Material properties: Q or Z? ---New experiments
• Direct determination of frequency : frequency shift
Direct measurement of frequency preference

**Frequency shift:**
We know that termites are attracted to foraging signals in larger blocks of wood.

We can alter the frequency information in the signal but retain the temporal structure → phase vocoder algorithm

Original

Pitch shifted
Manipulation of preference using geometry

Problematic!
Variability of wood and construction of geometry
Plausible mechanism: assessment of structures using vibrations.
Experiments in field and laboratory.

Problematic!
Bioinspired vibration sensors

Image (without permission) from:
Subgenual organ: tiny accelerometer?
DSP applications

Termites only have ~100,000 nerve cells in the central ganglion (pinhead size), yet are able to process vibratory signals buried in noise.

Distributed signal (pre-)processing

Depends on vibratory features used (e.g. Temporal/rate encoding vs. spectral encoding)
Parsimony of biologically based neural processors?

- Correlation with electrophysiological responses: better test validation
- Encoding type
- Information theory
- Limitations on processing efficiency of neural system (assessment and communication)
Thanks!

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Ra.Inta@anu.edu.au
Questions?