Sensor technology for tracking animal movement

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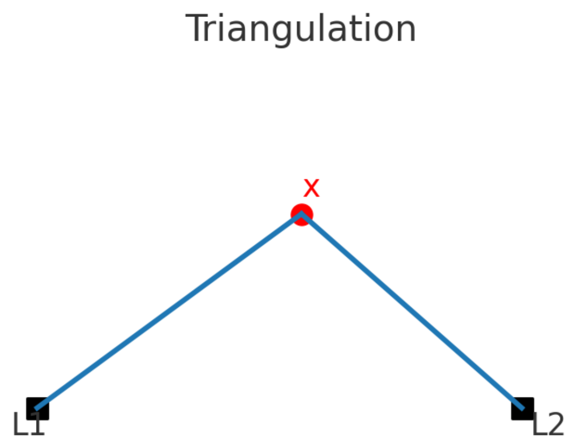
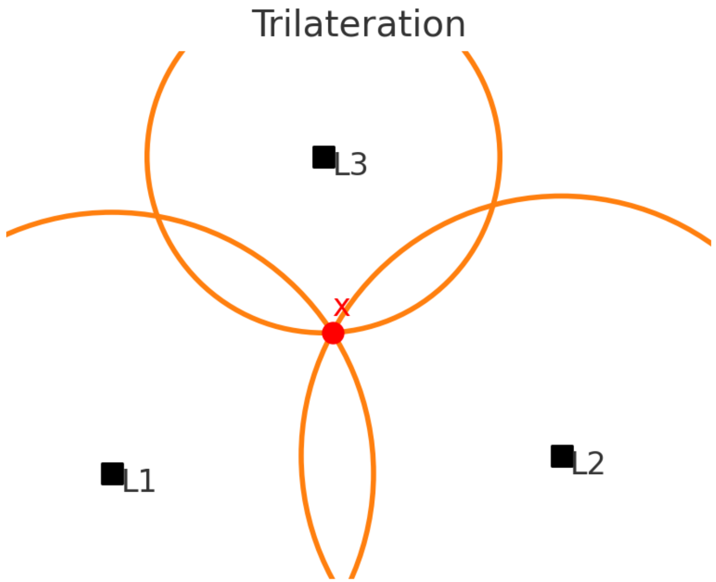
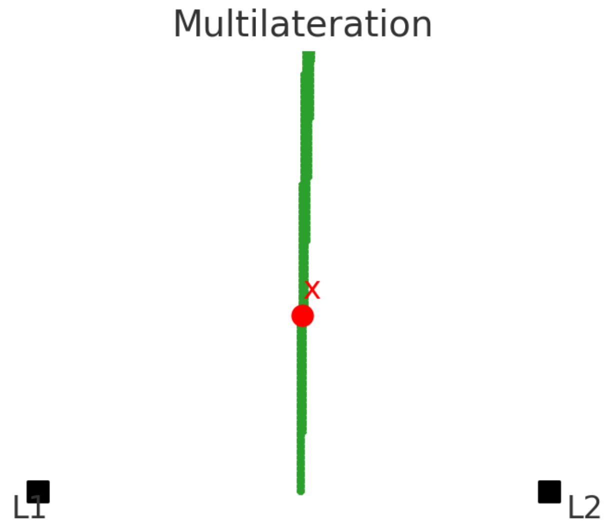
Principles

- Triangulation, using e.g. two *directions* to landmarks
- Trilateration, using e.g. three *distances* to landmarks
- Multilateration, using e.g. four *distances with one unknown offset*
- Odometry, dead-reckon speed and heading







How Animals Navigate

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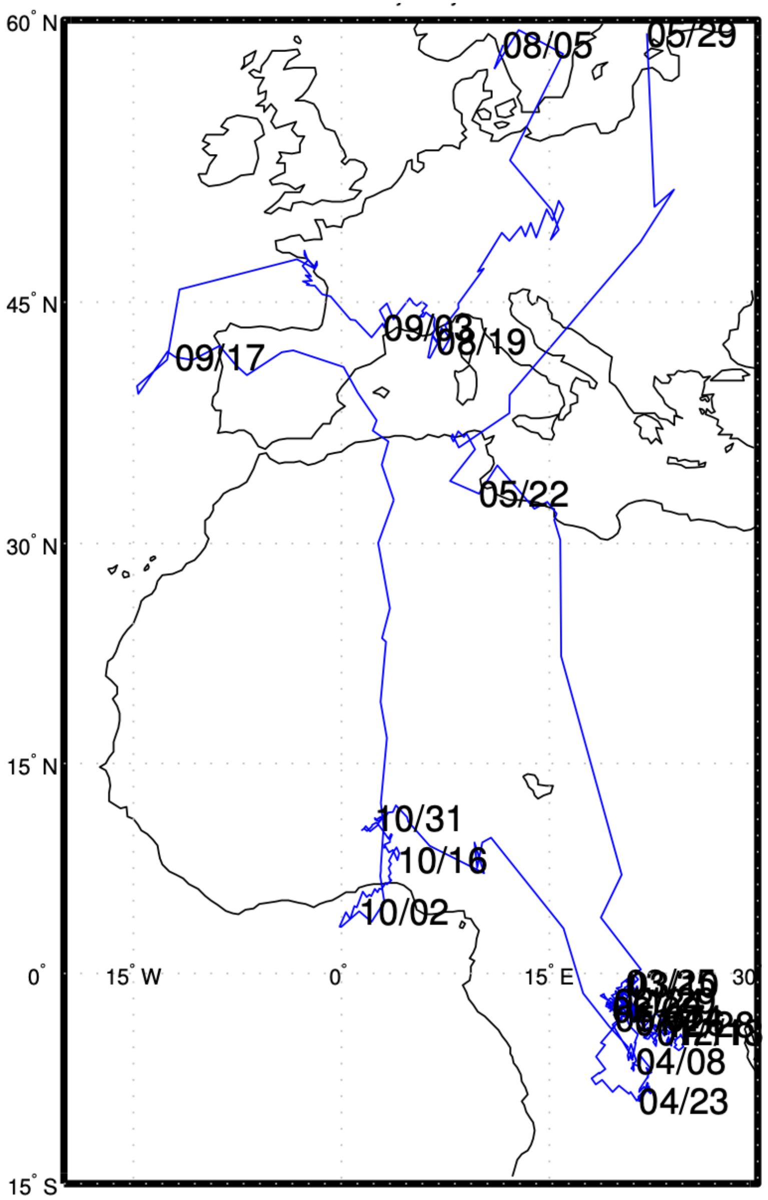
Animal strategy	Geometric principle	Technical analogue
Desert ants (path integration + sun compass)	Vector addition of displacements; angular triangulation	Inertial odometry fused with sun sensor or polarisation camera
Bees/wasps (snapshot homing)	Landmark matching; angular triangulation	Appearance-based visual localisation, lightweight visual place recognition
Bats/dolphins (echolocation)	Multilateration via TDOA of echoes	Acoustic or RF multilateration; radar/sonar positioning
Migratory birds/turtles	Magnetoreception and celestial triangulation	Magnetometer with anomaly mapping; star/sun trackers
Fish/bacteria (plume following)	Gradient ascent in chemical concentration fields	Electronic noses for leak detection, gas source localisation
Bird flocks/ant colonies	Distributed consensus and trail following	Multi-agent localisation, swarm robotics with low-bandwidth sharing

Light Loggers

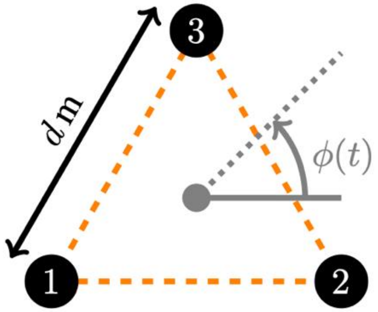
- Common Swift equipped with light logger at Lund University
- Memory card with light intensity read off when it returned
- Sun sets and sun rises estimated from light intensity
- Intuition: mid day gives longitude, day length latitude
- Kalman filter used to track position

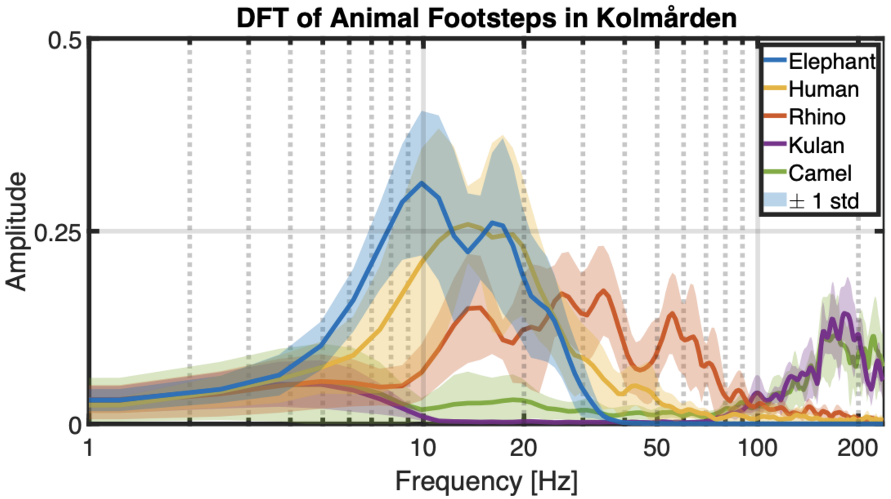


A Voyage to Africa by Mr Swift, Niklas Wahlström, Fredrik Gustafsson and Susanne Åkesson, Fusion 2012

Seismic Elephant Tracking

- Three geophones buried in soil
- Detects footsteps
- Computes Direction of Arrival





Seismic Detection of Elephant Footsteps. Daniel Goderik, Albin Westlund, Gustav Zetterqvist, Fredrik Gustafsson and Gustaf Hendeby. Fusion 2024

Radio Measurements

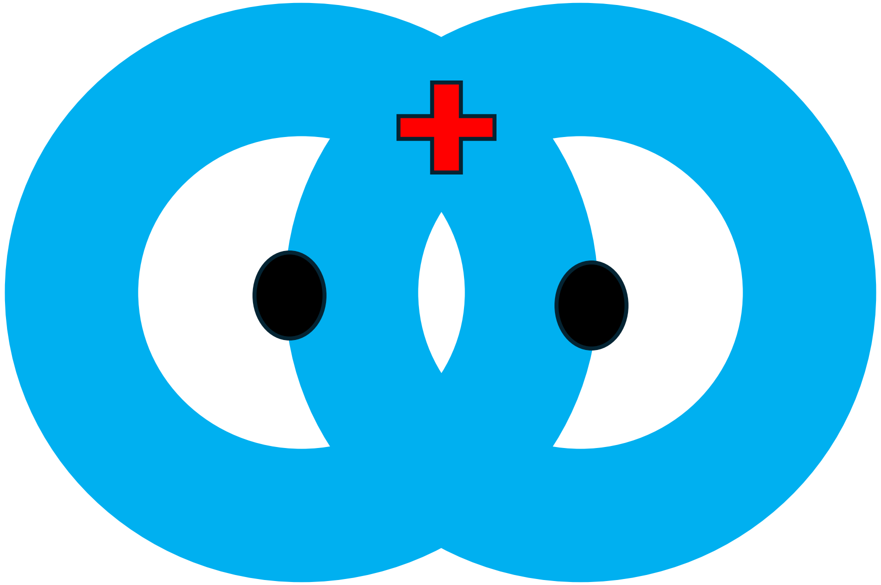
- RSS: Received Signal Strenghts
  - Decays with distance – trilateration
  - Forms patterns – fingerprinting
- DOA: Direction of arrival – triangulation
  - E.g. yogi antennas (Swe: pejl) gives DOA manually
  - Multiple antennas computes DOA automatically
- TOA: Time of arrival – trilateration
  - Rount Trip Time – RTT
- TDOA: Time-Difference of arrival – multilateration
  - GNSS Global Navigation Satellite Systems

Case Study: BLE

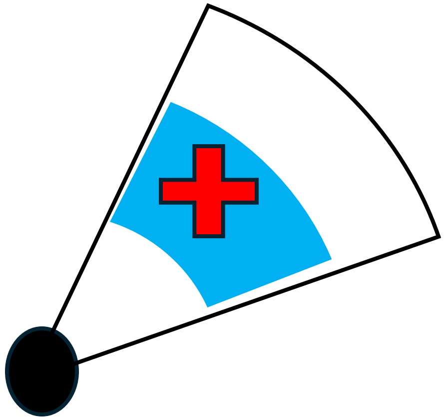
Bluetooth Low Energy variant of Bluetooth for IoT data

- RSS
- DOA in BLE 5.4
- TOA (RTT) in BLE 6.0

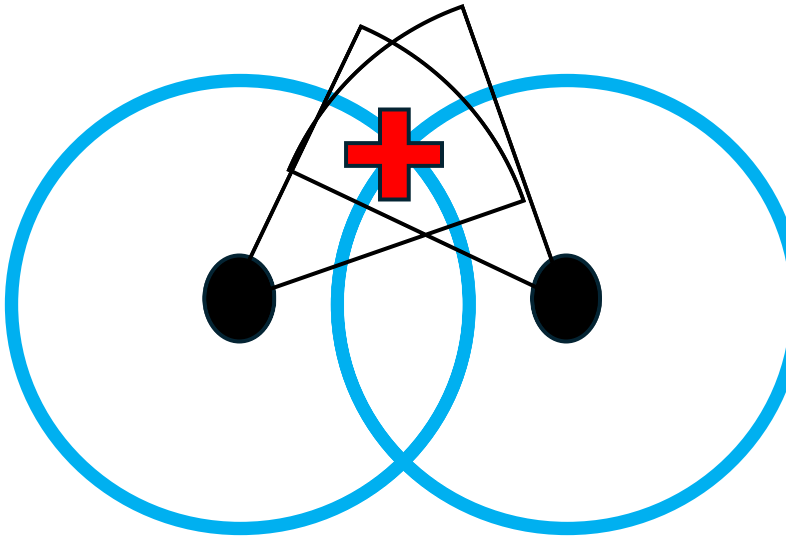
2 RSS



DOA + RSS



2 TOA + 2 DOA



Case Study: Indoor Localication

- Fusion of different information sources:
    - Dead-reckoning speed (steps) and direction (magnetic heading)
    - Fingerprinting of RSS from BLE beacons
    - Building Map
- Large research area from 2008 with many spinoffs, incl Senion (later Verizon) from LiU

Qulinda BLE tag

Tag

- Very small: PCB down to finger nail size
- Energy efficient: runs many year on a button cell battery
- Motion sensors: use accelerometer to log activity, e.g. step counter
- No GNSS, no long range communication

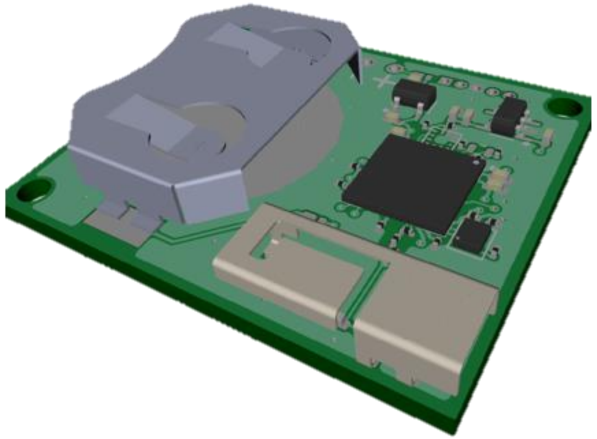
Scanner

- To co unt individuals in a herd (daily supervision of livestock)
- To find the collars the last hundreds meters (similar to VHF)
- To track animals in small enclosures, even indoors

Actuator

- Add-on to the BLE ear tag
- Speaker and vibrator
- Intended to control livestock within a virtual fence (without electric shock)
- Like getting a bumble bee in the ear!

36 x 26 x 4 mm



IoT Data Communication

Type	Range [m]	Energy	Data (Bytes)	Cost
RFID	0.1-1	None	ID only	Very low
VHF	1000-10000	Low	ID only	Medium
BLE	30-300	Low	256 + infinity	Low
LoRaWAN/Sigfox	1000-10000	Medium	256	Medium
Cellular	10.000	Medium	Infinity	Medium
SatCom	Infinity	High	low	High

Cellular Data Communication

Era	Milestone	3GPP Release	Release completion / freeze
2G (GERAN)	GPRS (packet-switched data)	Release 97 / 98	1999-02-12
2G (GERAN)	EDGE / EGPRS Phase 1	Release 99	1999-12-17
3G (UTRAN)	UMTS / WCDMA data (R99)	Release 99	1999-12-17
3G (HSPA)	HSDPA (downlink packet access)	Release 5	2002-09-12
3G (HSPA)	HSUPA (uplink packet access)	Release 6	2005-09-28
3G (HSPA+)	HSPA Evolution / HSPA+	Release 7	2008-03-13;
4G (E-UTRA)	LTE (first 4G LTE spec)	Release 8	2009-03-12
4G (E-UTRA)	LTE-Advanced	Release 10	2011-06-08
4G (E-UTRA IoT)	LTE-M (eMTC / Cat-M1)	Release 13	2016-03-11 (Rel-13 frozen)
4G (E-UTRA IoT)	NB-IoT (NB1)	Release 13	2016-06-21 (standardization complete)
4G (E-UTRA)	LTE Cat 1bis	Release 13	2017
5G (NR)	5G NR Phase 1	Release 15	2019-06-07
5G (NR)	5G NR Phase 2 enhancements	Release 16	2020-07-03
5G (NR/IoT)	**Non-Terrestrial Networks (NTN) for NR + IoT**	Release 17	2022-06-10 (ASN.1 frozen)
5G-Advanced	Further 5G evolution incl. NTN enhancements	Release 18	2024-06-21

Collar Tags

- Session at IWC Lillehammer last week between 100 wildlife researchers and 8 tag manufacturers
- Three requirements for the perfect tag:
  - Reliability.
    - Robustness. No beta testing in the field
    - Easy handling. Simple deployment and battery replacement
  - Modular design: simple base unit with a modular system design
  - Performance spec:
    - Small size for small animals and juvenils
    - Long battery life – many positions
    - High position accuracy
    - Reliable communication
    - Motion sensors (Acc, Gyro) for activity analysis

Qulinda Tags

- Reliability
  - We use tags from Digital Matter in South Africa. These tags have been manufactured in millions and tested in all environments.
  - Qulinda tests every unit before sending them plug and play, with batteries and SIM card and registered in our system
  - About 99% of all tags work after one year
- Modular design
  - Yabby Edge default, with longest battery life
  - Other models with better GPS, other communication (4G, LoRaWAN), available
  - Tailored 3D-printed neck adapters for small animals
  - BLE module as backup
- Performance.
  - Around 30m accuracy, 80% position fix for Yabby Edge, almost 100% 4G reliability in Sweden
- New own platform
  - 4G, 5G and Satcom (NTN)
  - Acc, gyro, temp, humidity sensors
  - Small size, 50x25x20mm with smallest battery

84 x 63 x 24 mm

Yabby Edge: Battery Budget Example

- How the battery is used when sending one position per hour

Power consumer uAh	Yabby Edge
Battery capacity 3 AAA	1,6 x 3 = 4.8 Ah
Cost per upload connection	47 uAh
Cost per record upload	1,2 uAh
Cost per Gps Satellite scan	16 uAh
Cost per hour of sleep	4,3 uAh
Sum Ah/h @1pos/h	~70 uAh
Ah per year @1pos/h	0.6 Ah

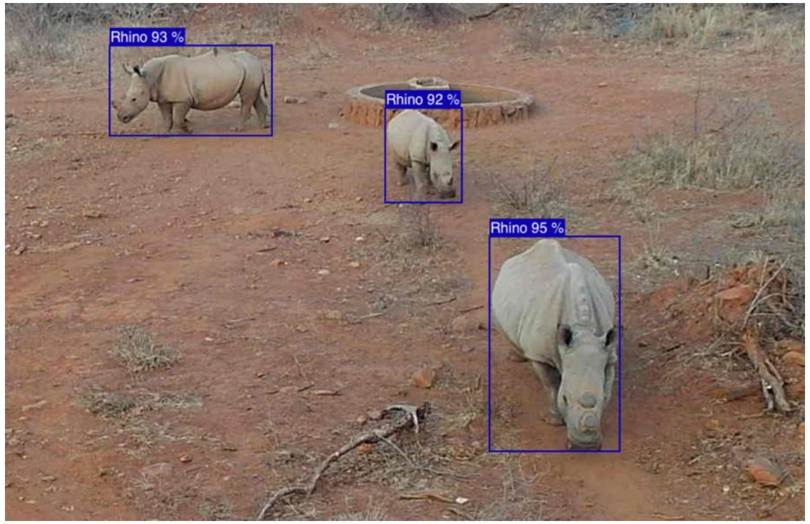
Tracking and Activity Tags

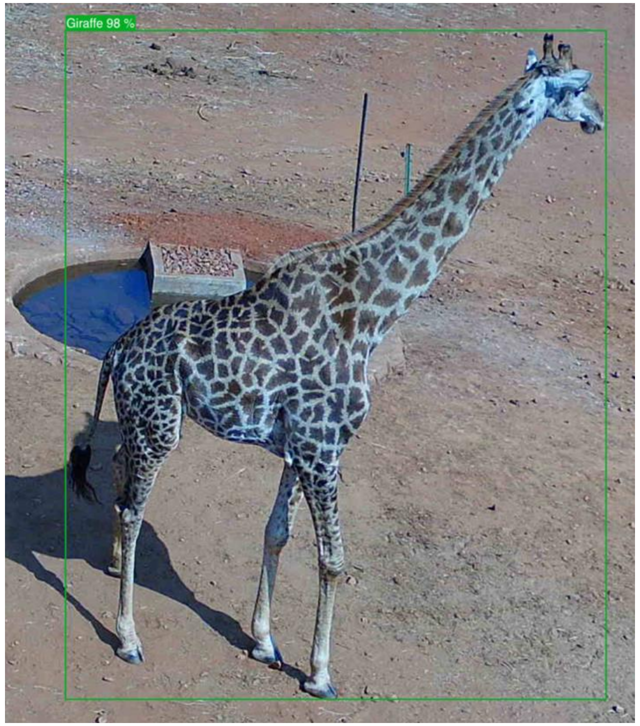
Fundamental Limitations

- Battery – energy density.
  - No known battery technology with kWh/kg capacity.
  - Li-Ion 0.5 kWh/kg
  - Fuel as 10+ kWh/kg
- Radio propagation has physical limitations in range
- Antenna size inversely proportional to frequency

Machine Learning for Images

- African model, with focus on endangered species and human wildlife conflict

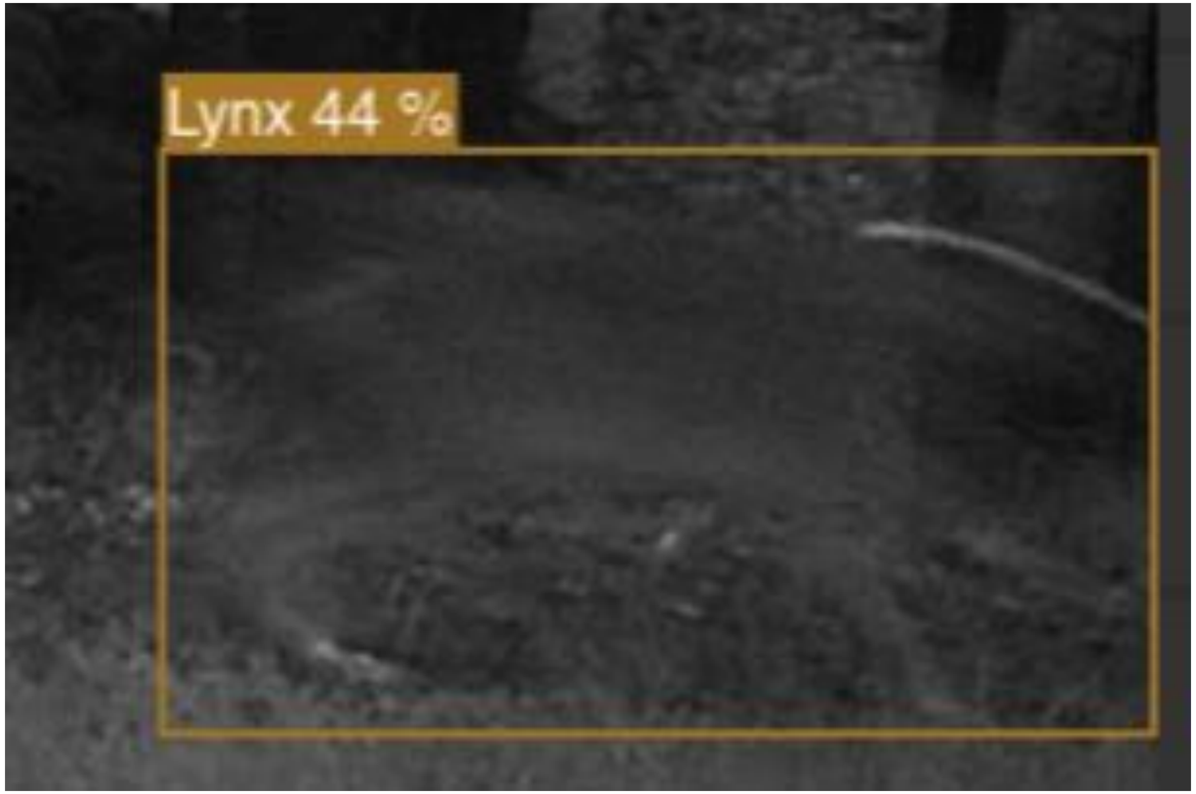




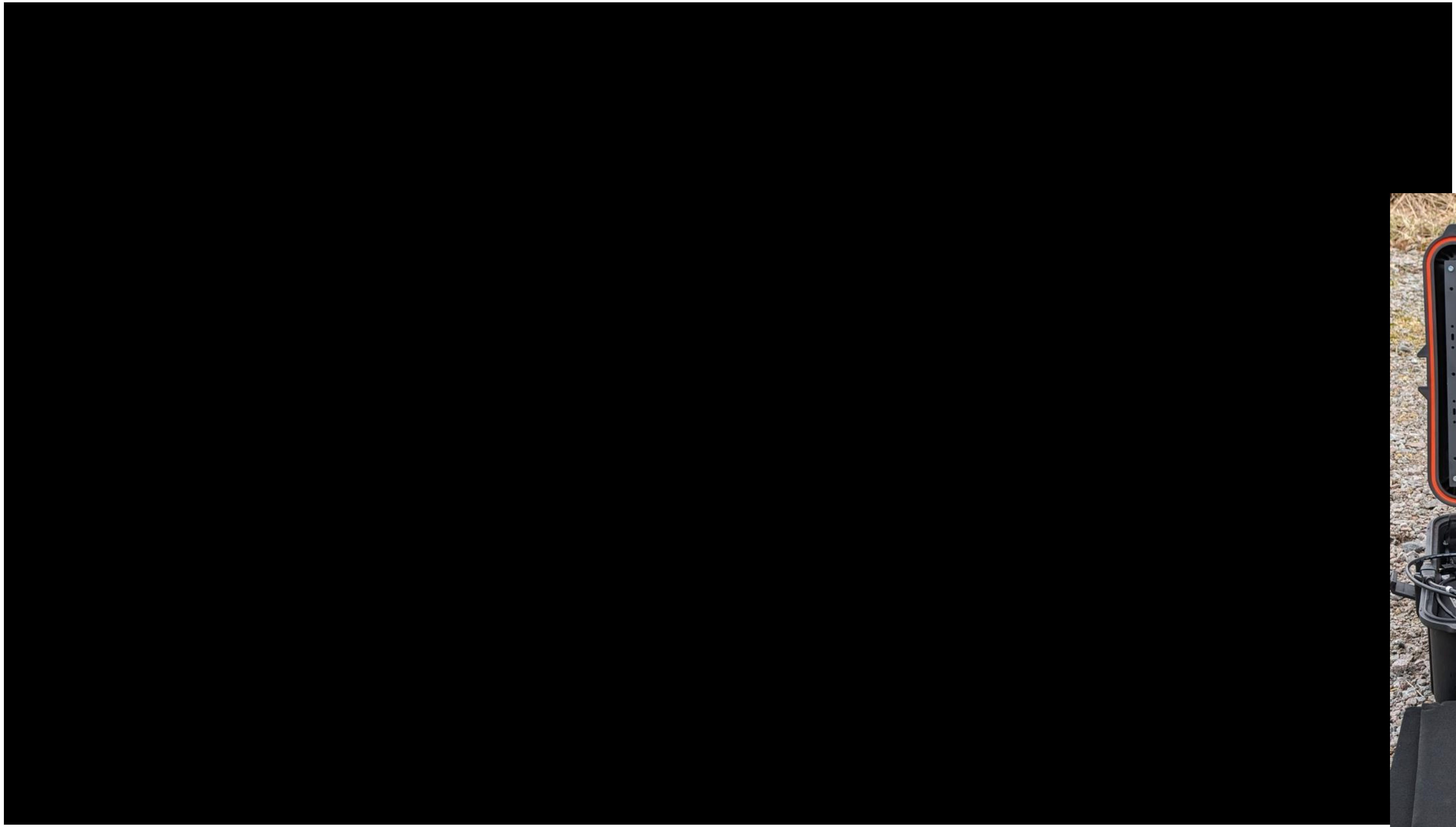
Machine Learning for Images

Swedish model for our large mammals

- Pest control for farmers
- Wildlife monitoring

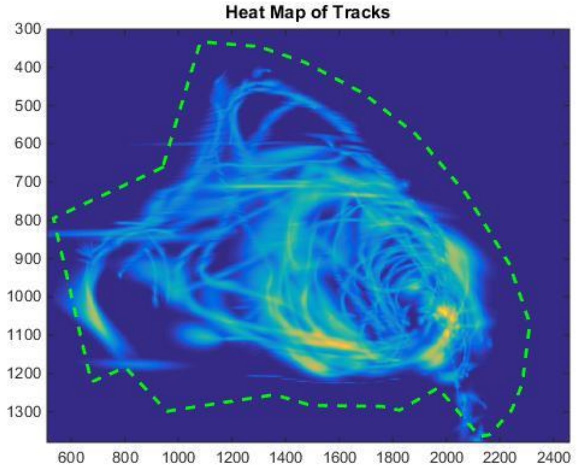


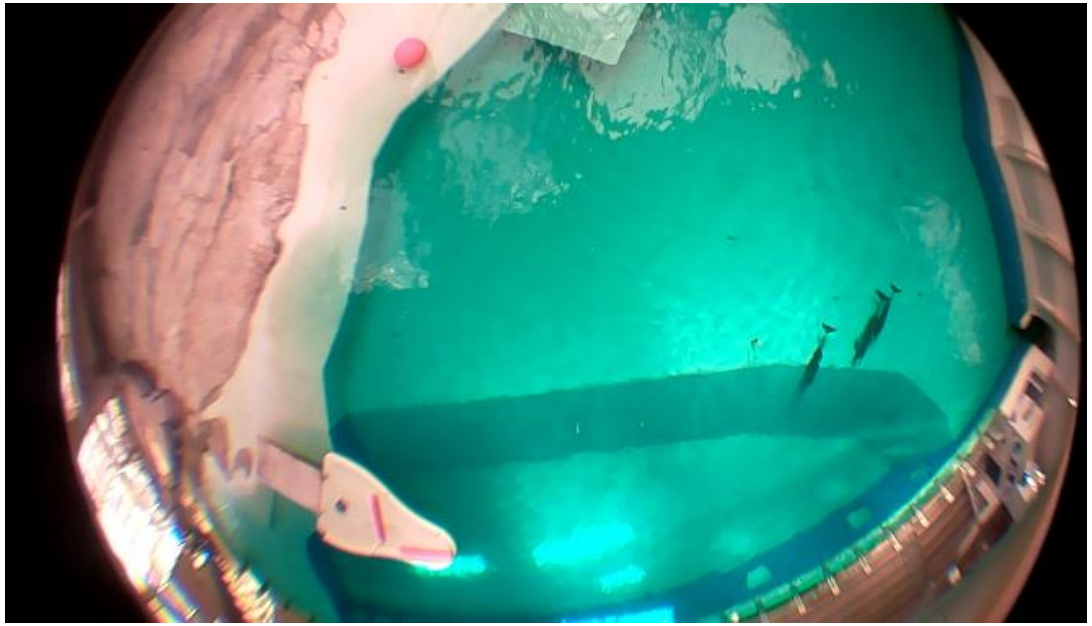
Tracking from Drone Video

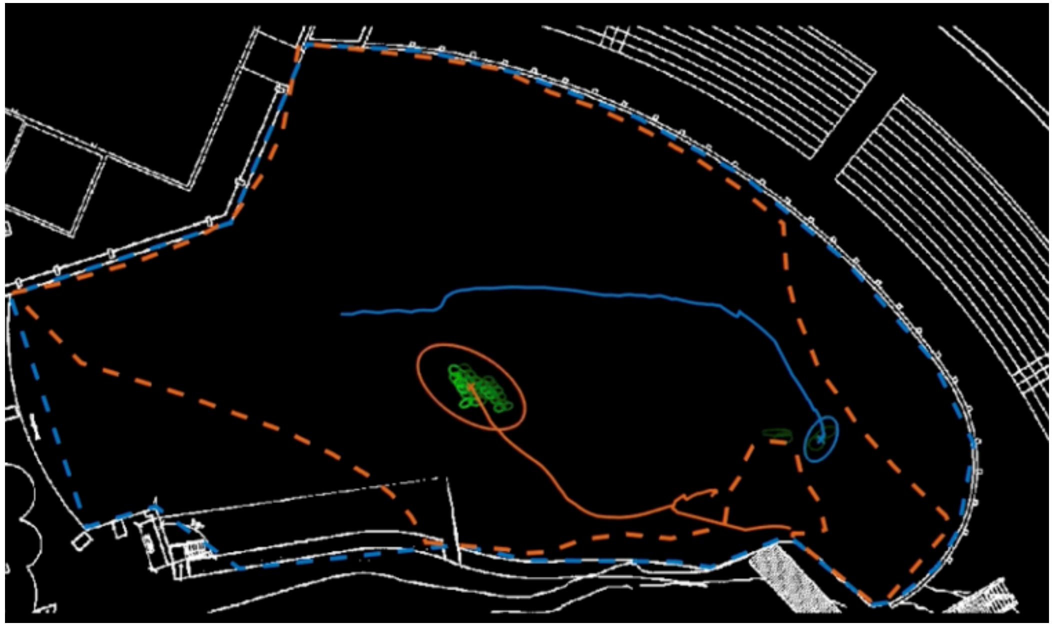


Tracking Dolphins

- One wide angle camera mounted in the laguna ceiling at Kolmården Zoo
- ”Heat map” based on longer period of tracking of two dolphins in the Laguna. Youtube movie
- Momentary view of an ongoing tracking of a dolphin in the Laguna



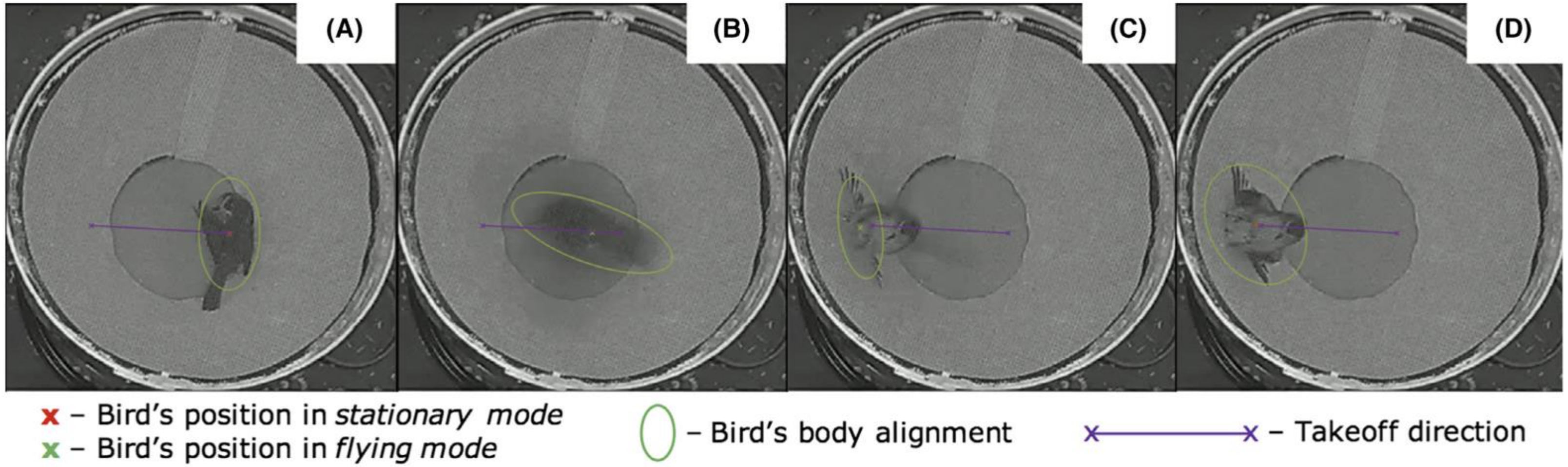




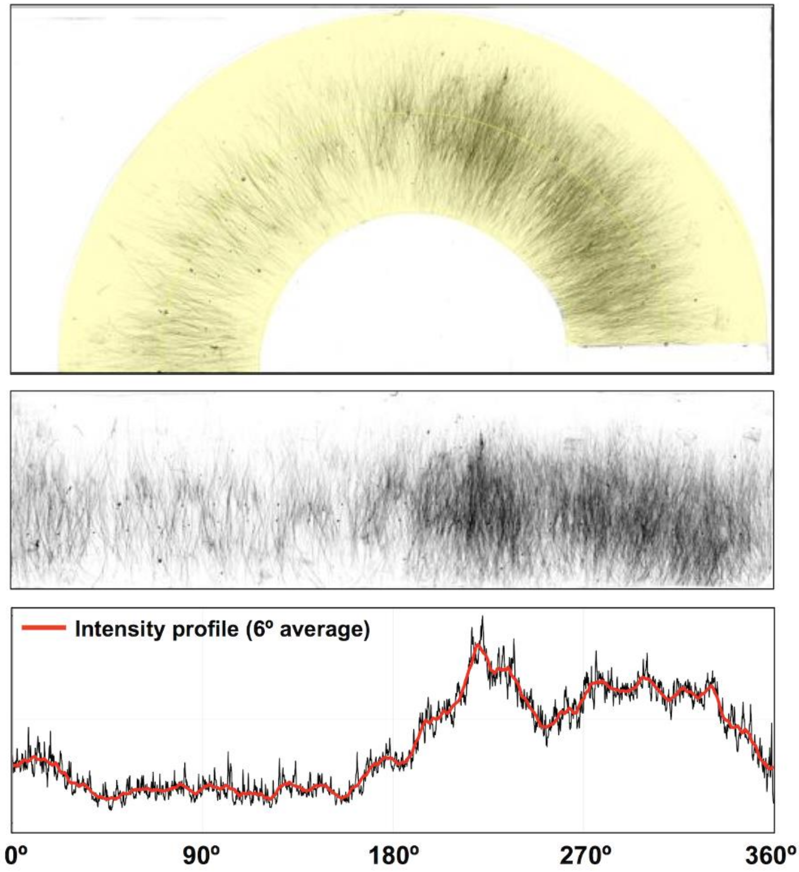
Veibäck, C., Hendeby, G. & Gustafsson, F. (2015). Tracking of Dolphins in a Basin Using a Constrained Motion Model. Paper presented at 18th International Conference of Information Fusion, Washington, D.C., USA, July 6-9, 2015
Laura van Zonneveld (2016): The importance of acoustic enrichment for bottlenose dolphins (*Tursiops truncatus*) in human care. Master’s thesis LiTH-IFM- Ex--880416/T324—SE.

Emlen funnel

- Emlen funnel used to study how migratory birds (here European robin) try to escape from a cage
- A downward looking camera was used to analyse the movements of the bird.
- Both the body and beak of the birds were tracked simultaneously.
- Migratory birds are supposed to have a built-in compass. The idea with a Emlen funnel is to verify this hypothesis by uncovering the cage and study which direction the bird heads off.



Classical approach with claw mark analysis



[Emlen funnel experiments revisited: methods update for studying compass orientation in songbirds](), Giuseppe Bianco, Mihaela Ilieva, Clas Veibäck, Kristoffer Öfjäll, Alicja Gadomska, Gustaf Hendeby, Michael Felsberg, Fredrik Gustafsson, Susanne Åkesson