Wildlife Tracking on the Wing Using Unmanned Air Vehicles

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The miniaturisation and increasing accessibility of tracking technology is transforming the fields of animal behaviour and ecology. Studies involving animal movement are shifting from sparse observational data to high-throughput, dynamic, precision time series for individual animals and groups. However, a combination of high cost, high mass, and inflexibility currently limits deployments of state of the art devices such as Unmanned Air Vehicles (UAVs) to track more species or at greater scales. The recent uptake of low-cost logging devices has demonstrated the appeal of low-cost approaches, but these devices are necessarily limited by the need for field recovery. Here, we describe the concepts of a novel, low-cost, and wirelessly enabled UAV tracking platform that allows researchers the flexibility and power to tackle a variety of novel research questions. The novel application of the system is the following; 1) To track multiple individual animals within a free-moving group simultaneously, 2) To allow freedom from data retrieval efforts by collection of the wildlife movement data on-the-fly, 3) To allow tracking of hard-to-detect individuals by data sharing and collection from highly mobile, easily accessible endangered species.

Abbreviations

GPS	=	Global Positioning System
UART	=	Universal Asynchronouse Receiver / Transmitter
UAS	=	Unmanned Aerial System
UAV	=	Unmanned Aerial Vehicle
UHF	=	Ultra High Frequency

I. Introduction

The movement and spatial dynamics of individuals, their interactions, and the association between their movements and environment is vital for our understanding of diverse behavioural, ecological and genetic questions[1,11]. Gathering such information is acutely relevant for species that may be vulnerable to environmental change, as our understanding of the relationship between environment, movement and distribution is often unclear. However,

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current tracking technologies are often expensive, inflexible, unsuitable (high mass, restricted functionality, large size), and can be labour intensive, limiting both the applicability and scale of ecological and behavioural studies.
A variety of devices are available to record the movements of species without the need for recapture. Transmission of data via satellite or radio is often used for tracking of migration and juveniles[2]. While these technologies allow researchers to receive data remotely via satellite or UHF radio, they are expensive. However, in many cases, these platforms have proved indispensible, especially for recording the movement of animals over large distances when they are unlikely to return in time for devices to be retrieved e.g. Bar-tailed godwits Limosa lapponica[3]; leatherback turtles Dermochelys coriacea[4]. Recent advances have also shown that local radio communication can enable data download from animal-borne devices[5, 6]. However, these systems are still often prohibitively expensive for larger scale research (for estimated costs, see Ref 2), and tracking parameters are often limited by the manufacturer (as devices are generally produced either for commercial or consumer use they are usually not reprogrammable). As such, the range of tracking options that can be varied (sleep/wake period, logging frequency) is limited and more complex changes need to be requested from the vendors (and may not be possible). A system that provides greater flexibility, allowing researchers to reprogram devices as needed, would open up the possibility of a range of novel sensing approaches. For example, programming devices to record data when particular conditions are true (in a given location, moving at a given speed, likely to be in a particular model state), or to vary the frequency of logging, or to communicate information with other devices when such conditions are met. The options should be limited only by the capabilities of the hardware and the programmer, not the manufacturer's choice. Enabling this intelligent sensing, and making it straightforward for the experimental investigator to use, would provide a powerful new tool for research.

The availability of low-cost bio-logging devices, such as light-level geolocators, or consumer GPS loggers, has also precipitated a dramatic recent growth in the number of tracking studies[7,8,9,10]. These archival devices are however limited by their need for recovery in the field. In such cases, the variety of species that are addressed tends towards those that are easily recaptured and are less likely to be stressed by repeated disturbance.

To address these problems, we present an open, reconfigurable, wirelessly enabled, low-cost tracking technology. Amongst many possibilities, this system can enable data retrieval via wireless link without the need to recover devices and can enable device-device communication during deployment, even in flight. Our open-source, open-hardware approach provides a framework for researchers who wish to explore novel tracking approaches to develop their own applications.

To demonstrate the system, we focus on an examples scenario that poses significant field challenges. We have proposed this methodology in order to absorb fund and wildlife research partner so to be able to implement the proposed solution.

II. Methodology

The platform consists of the following components;

1. A small electronic data collection device; the device would include a few environmental sensor as well as microprocessor, memory, GPS receiver, and a radio module. Each animal under study would be captured only once to attach a device. The device also includes an automatic release mechanism to drop off the animal under certain conditions. Of course the device would include a battery and power management software mechanism to allow management of the operation life of the device.
2. A small electronic base station device; the base station collects the data from the data collection devices using the radio module.
3. A UAS that takes the base station as its commend and control unit in order to move towards the range of the radio communication with the data collection devices when required.

Figure 1 shows a schematic of the conceptual design. Data collection devices on the speieces under the study would hold a firmware responsible for sampling and logging data from onboard sensors based on a schedule controlled per study. The firmware would also be responsible for etsblishment of the radio communication between two devices.

Base station device would sit on the UAS and serves as command and control unit. It communicates on one hand with the data collection device and on the other hand with the autopilot system of the UAS. The collected data from the data collection device allows the base station to understand the location as well as the past trajectory of the animal or animals that the gathered data came from. This in trun allows the base station to decide the best location that the UAS could fly to in order to communicate with the data collection devices most effectively.

The base station is also in charge of understanding the weather conditions from the collection of the onboard sensors, i.e. rain sensor, wind speed sensor, pressure and temperature sensor. The UAS flys according to the flight path and permission to fly taken from the base station.

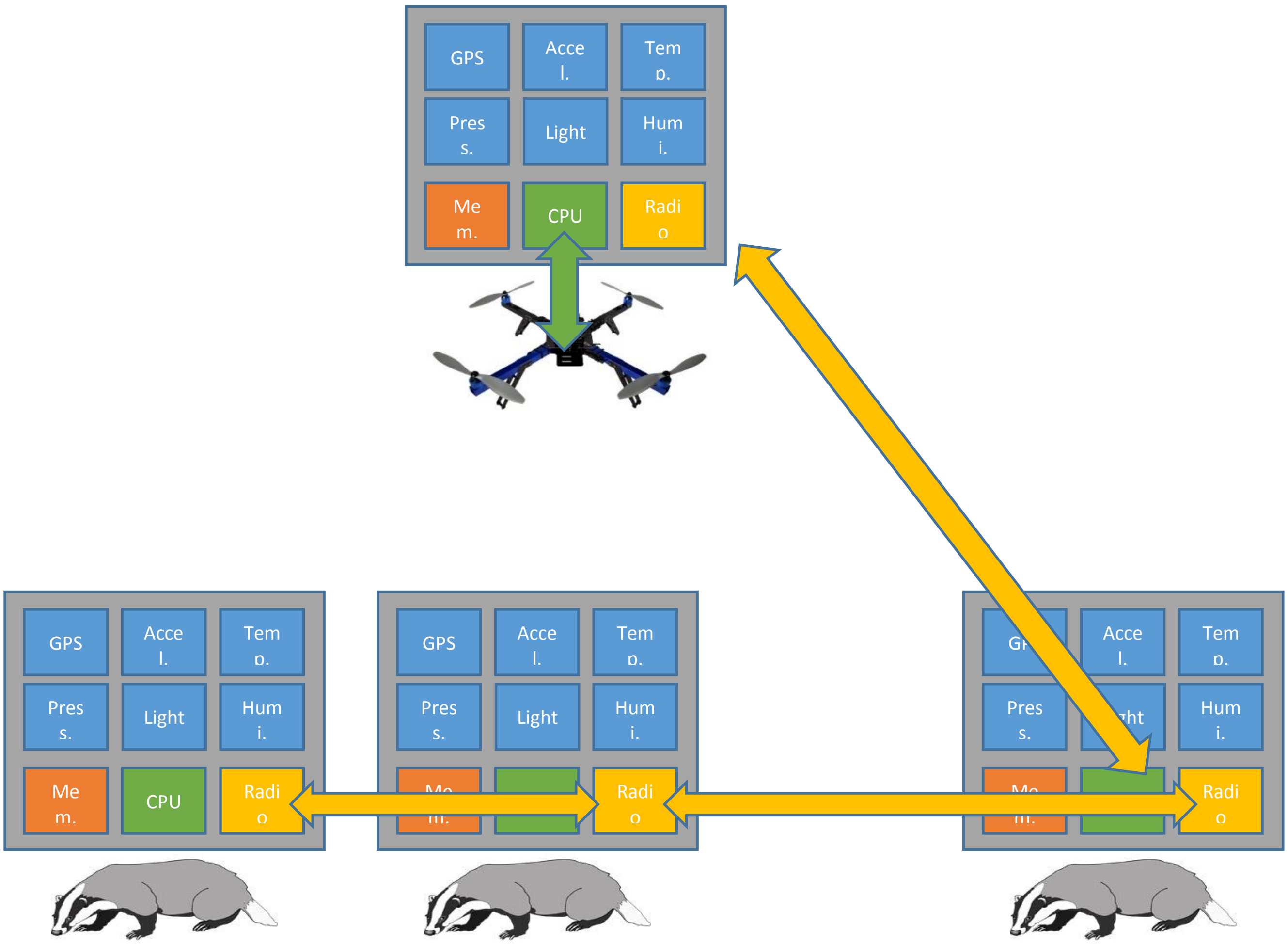

Figure 1 Wildlife Data Collection using UAS

III. definition of the project

A. The aim and objectives

The aim of this project is to use smart tracking devices to determine the home ranges, movements and fine scale habitat selection by Badgers. We will determine and characterise in details the habitats in terms of daily rhythms and changes in movements / space use. Questions such as the following;

1) What corridors do Badgers use to travel between locale patches?
2) What distances do they travel?

3) To what extent do they utilise transformed land?
4) How far and for how long do they stay outside of prime habitat and where exactly do they stay?

These novel and detailed data will contribute to a better understanding of the impacts that current land use changes and habitat fragmentation have on Badgers, especially when dispersal patterns coincide with industrial pollutions and human/wildlife conflict. So to identify suitable habitats beyond our study areas and better inform conservation actions focused on habitats.
The generated movement data will be shared on Movebank.org and with local stakeholders in order to give new insights on the ecological and reproductive requirements of the species under study.
Anticipated results of this project will be habitat suitability map. This project will provide information about used and selected habitats and environmental factors related with this selection. This information will be used to perform a habitat suitability model in order to identify potential habitat which must be protected on entire landscape.

The aforementioned conceptual design is under development at Civic Drone Centre of University of Central Lancashire. The current status of the platform is a set of tracking tags, the completed data collection software, UAV with sufficient reliability to take a base station onboard and communicate with in order to take flight trajectory in real-time.
Three application were recently proposed to apply the method for habitat study of Otters, Badgers,and Tasmanian Devils. The follow up papers will report the design, the implementation issues, and the analysis of the results.

B. Detailed account of the proposed methodology

The animal tracking method has the following workflow: Scan terrains to detect animal presence, model the probability of animal occupancy, collar, release and track animals, data acquisition and data analytics, Spatial-Temporal Habitat modelling and model future management scenarios. Each of these steps is described in more detail.

1. Scan terrains to detect animal presence: Utilisation of UAV remote cameras to determine the distribution, habitat use, and probability of occupancy for Badgers. We will sample for Badgers by deploying remote cameras, along with bait and scent stations targeted for Badgers, throughout multiple study sites across Tasmania.

2. *Model the probability of occupancy of Badgers based on habitat characteristics* (e.g. habitat type, level of fragmentation): this is derived from remotely sensed imagery. This process will result in a preliminary understanding of what type of habitat Badgers are using. It will also provide us with information on where to trap for Badgers to apply the tag units.

3. *Collaring, release and tracking of the Badgers*: Fifteen Badgers will be ethically tag collared. Each animal will be fitted with a tag and released after full recovery from sedation. Animals will be continuously tracked for three months. Regular tracking will be done by a combination of installing eight receiver tags at certain points in the habitats and two receiver tags flying on two multirotor UAVs in a pre-programmed and controlled way.

4. *Data Acquisition*: We plan to collect tag-based Badgers locations at two different temporal scales. The fine-scale data collection will be implemented approximately once a week for roughly an hour, collecting one point every 1 to 5 minutes depending on restrictions associated with battery life. The timing of these one-hour sessions will likely vary week to week within the Badgers's peak activity times. The coarse–scale data collection will be implemented continuously, collecting locations approximately once or twice per day, again depending on battery limitations. This coarse-scale data collection will be essential for matching daily movement patterns of virtual Badgers to the real-world movements recorded in the field. Aside from the modelling component, however, we will use this GPS data to determine what type of habitat Badgers are using relative to the occupancy probabilities of other meso-carnivores that were derived from the camera trapping phase of the project. This application of the GPS data will therefore validate or dispute the conclusions that were made from the camera phase of the project about which species are in competition with Badgers and could therefore be limiting their population growth and dispersal. This GPS data will also allow us to determine what impact habitat fragmentation has on the movements of Badgers.

6. *Data analytics* is used to determin ranging behaviour, activity pattern and habitat preference elucitation. Data obtained from the collars will be used to analyse the ranging behaviour and activity pattern of each collared species. Habitat map of the study area will be prepared from the recent satellite images and vegetation assessment in the field. The GPS locations obtained from the collared animals will be used for the assessment of habitat preference.

7. Spatial-Temporal Habitat modelling: The final phase of the project will involve utilizing a spatially explicit individual-based population model developed by the Zollner lab at Purdue University[12]. It incorporates a number of parameters about the animal population being modelled (e.g. distance moved per time step, probability of mortality, fecundity, activity patterns, etc.) and simulates dispersal by individuals across a landscape based on those parameters. SEARCH represents an advancement in spatially explicit simulation of dispersal because it incorporates an unprecedented amount of behavioural and spatial temporal complexity while simulating dispersal across large areas and tracking changes in population numbers over long time periods. However, meaningful and accurate incorporation of that complexity requires intensive empirical data on animal locations that will be available using GPS telemetry. For example, SEARCH simulations include modelling of movements, survival, and reproduction of each individual in the population as each virtual animal makes decisions and uniquely experiences the virtual environment based on the input parameters and characteristics of the landscape. These landscape characteristics exist on 4 different maps that are provided by the user, and across which the individuals are traveling. These maps specify movement rules, habitat suitability/availability, predation risk, and food availability. Essentially, the animals disperse across the landscape until they find an area void of conspecifics and suitable for home range establishment. In order to create the best possible virtual Badgers that models the decisions and life history of real Badgers, we need the most accurate parameter data that we can obtain. This is where the fine-scale GPS data collected in the second phase of the project is critical. SEARCH is capable of modelling distance moved as well as the directional change in movement at a scale as fine as one minute (note that the length of each time step to be modelled is defined by the user) but accurate representations of movement in SEARCH require the data from the GPS collars. In addition to the fine-scale parameterization, we will also use the coarse-scale GPS data to match the overall daily movement rate within SEARCH to the patterns of movement exhibited by real Badgers, thereby informing us of the reliability of our resulting simulation models.

III Preliminary Results

Results of an early field deployment to track the foraging behaviour of the Common Guillemot is shown in Figure 2. While 11 of the 16 devices were not physically recovered, data was successfully recovered from 15 devices during the deployment. Figure 2 shows the recorded tracks that were autonomously downloaded via base-stations at the colony. In general, tracks from 1-3 foraging trips were recorded for each individual, with Figure 2 showing a single example where available. Individuals tended to travel out to 30-50km from the colony before returning.

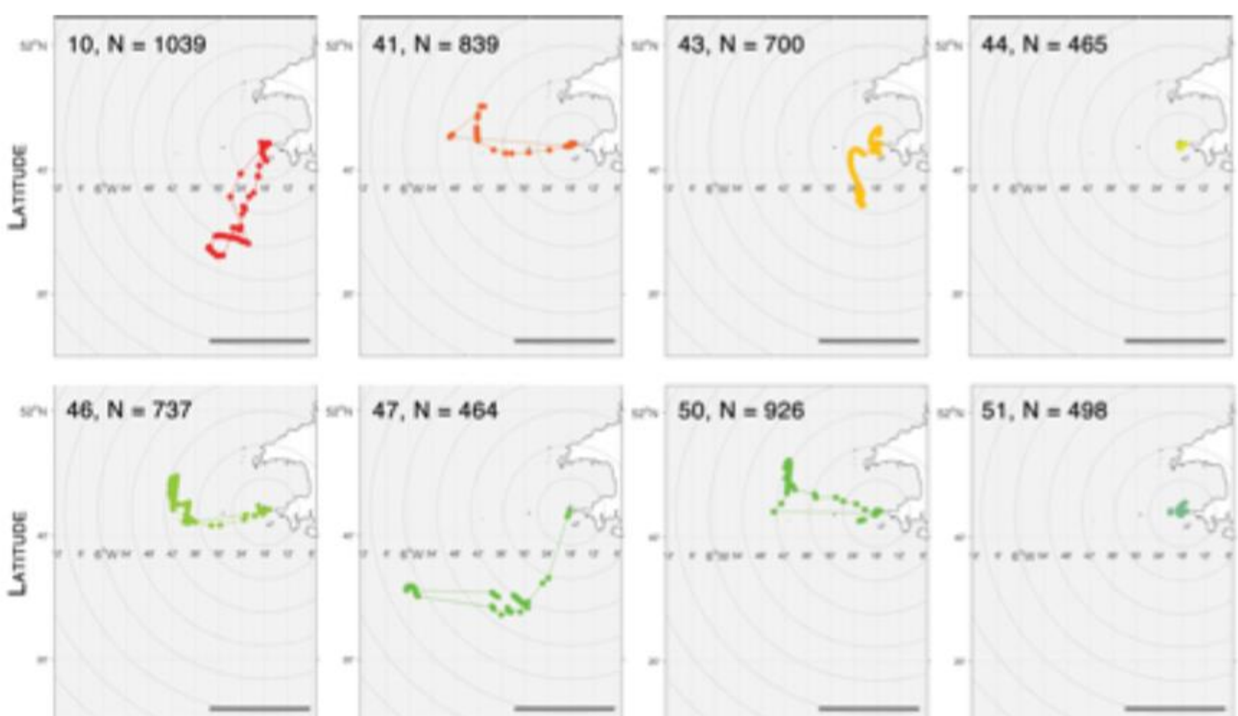

Figure 2 Individual tracks recorded from foraging Guillemots. Each panel shows the tracker 472 identification number, and the number of points recorded for that individual (N). Tracks are overlaid on 473 10km concentric circles from the colony. The final panel in the bottom right shows all the tracks and the 474 total number of points recorded. Horizontal grey bars at bottom right denote a 30km distance.

The early results of some trials has encouraged the improvement of the data collection software to include hopping mechanism for collection of data from tracker to base station more effectively. Precisely speaking, the implemented hopping mechanism allowed trackers to pass data to each other as well as to the base station whichever met earlier. This has increased the chances for data collecton from more species. This is being discussed in a separate paper in more details.

In addition, the early trials resulted the improvement of the antenna of theradio module on the data collection board. Multi-core copper wire antenna of certain length, i.e. 97 mm, proved three times mmore effective than single core copper wire antenna of the same size, i.e. a quarter of the transmission frequency (868 MHz).

Amongst the established infrastructure of the current platform is also the software component in charge of the communication with the flight controller module on the UAV. The communication is implemented using the MAVLink protocol over UART interface.

IV Conclusions and Outlook

It is highly desirable to complete the proposed methodology with modelling future anaiml management scenarios; Once we have calibrated the best possible virtual Badgers, it can then be used to model future management scenarios and their impacts on Badgers. For instance, suppose a new highway is proposed to be built through ideal Badgers habitat. By replacing the then-current movement map with a map that includes the proposed structure, we will be able to predict the likely impacts of that road on the Badgers population in the area. Alternatively, suppose managers are considering controlling populations of one of the Badgers's competitors. By adjusting the predation risk map, we will be able to provide Badgers population projections based on various scenarios of predator control. Beyond the specifics of the model system case study of Badgers in Tasmania this work will be a novel approach to investigating questions about interactions between meso-carnivores and in particular the implications of competitive release and cascading impacts of interactions between species. The combination of multi-species occupancy modelling with fine scale movement data from GPS collars in a new innovative individual based modelling approach represents a revolutionary combination of new approaches being used to investigate these questions. Insights from this new combination of approaches will provide great opportunities to improve both the management of Badgers and more broadly our understanding of how meso-carnivores interact with each other.

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