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Robots in Terrestrial Ecological Surveys

Grasslands

'Bots on the Ground vs Boots on the Ground: The Future of Robots in Terrestrial Ecological Surveying

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At the 2023 CIEEM Modernising Ecology conference, a robot greeted the attendees as they arrived. Was it a glimpse into the future?

As with other technologies, robots have the potential to revolutionise ecological surveying, yet this comes with both optimism and concern about possible impacts on our work. To explore the potential of terrestrial robots, as a group of ecological consultants, research ecologists and roboticists, we participated in a workshop organised by Edinburgh Napier University in 2022. This discussion highlighted some specific areas that might present the greatest opportunities or challenges for robots in terrestrial surveying. There was consensus that robots are likely to allow collection of more, better quality data in many areas, and to do so more safely, thus reducing human risk.

Figure 1. It's Christmas 2050 and CIEEM CEO Sally Hayns welcomes CIEEM's latest member. Photo credit: Mark Nason.

Introduction

Technologies such as eDNA, camera trapping and acoustic monitoring are changing how we collect ecological data. Robots have the potential to revolutionise ecological surveying in the future. Robots have three key characteristics: they (1) interact and/or locomote, (2) sense or perceive the environment around them and (3) have an onboard computer. A critical ability of a robot is the capacity to autonomously react to its surroundings by processing signals from its sensors. This contrasts with remote-controlled systems with a human operator (such as a remote-controlled drone or rover), or an automaton that repeats the same task but does not react to a change in the environment. As well as addressing the ethical challenges of environmental robots, van Wynsberghe and Donhauser (2018) focused on the question of the types of existing 'environmental robots' and proposed a taxonomy (Table 1). This draws a distinction between robots-*in*-ecology,

Table 1. A taxonomy of environmental robotics proposed by van Wynsberghe and Donhauser (2018) although, as indicated by the authors, none of these categories are exclusive.

Type of environmental robot	Description
Robots-*in*-ecology	"Robot technologies used for environmental research applications; including use of *general robots technologies* for such research."
Robots-*for*-ecology	"…a subclass of robots-in-ecology that are s*pecifically designed* to carry out, usually tedious (e.g. repetitive) or difficult, research-specific tasks that they can accomplish more efficiently than human researchers." Includes robots that "have been *designed, programmed, or somehow retooled specifically* to accomplish specialised environmental research tasks".
Ecobots	"Exhibit ecological functionality … either by playing some functional ecological role (e.g. serving as a proxy predator) or by augmenting ecological functioning (e.g. enhancing ecosystem services)."

> **Robots have the potential to revolutionise ecological surveying in the future. A critical ability of a robot is the capacity to autonomously react to its surroundings by processing signals from its sensors.**

robotic technologies that have been used/developed in other fields, but which have been adapted for ecological purposes, and robots-*for*-ecology, those that have been specifically invented/designed for some specialised tasks in ecology.

Operating ground-based robots in terrestrial environments is challenging. Nature is cluttered, has gradients of colours and undefined shapes, and lacks clear limits between elements of the environment, making it difficult to process and perceive images. Terrain is typically uneven, irregular and dynamic. There is likely to be risk of damage, and power management is a challenge. A government-funded UK Robotics and Autonomous Systems Network white paper published since the workshop (Davies *et al*. 2023) identified that terrestrial environments offer particular challenges for robotics and this was identified as a critical area of development to supporting biodiversity monitoring and conservation in the UK and beyond.

The development of robots in terrestrial ecological monitoring is still at a very early stage. At internal meetings of Edinburgh Napier's Centre for Conservation and Restoration Science (CCRS), ecologists and roboticists began to brainstorm the use of robots to facilitate and improve terrestrial fieldwork. To help inform future development and discuss potential applications and constraints in professional ecological surveys, a workshop was organised by CCRS in 2022, bringing together two roboticists, three research ecologists and eight ecological consultants (the authors). Several questions were asked at the workshop (summarised in Box 1). We report on four themes that emerged during these discussions, hoping they will stimulate further discussion and ideas among CIEEM members. Although the workshop was held 3 years ago, and some aspects of artificial intelligence (AI) have rapidly advanced, this has not been as notable with robotics, particularly in the terrestrial sphere.

Box 1. Overarching questions posed during the workshop.

1. What current ecological survey tasks do you think robots could carry out (to the same or better standard than people)?
2. What novel ecological survey needs do you think robots could meet that current resources/technology do not allow?
3. What constraints or risks do you see in using robots to do ecological surveying?

Theme 1: do we need ground-based robots?

There was some initial scepticism about the ability of ground-based robots to move in a terrestrial environment compared to water (e.g. submersibles) and air (e.g. drones), where fewer barriers exist. Challenging environments are not just about topography, but also vegetation (e.g. trees, tall wet grass, crops, bramble) and exposure to weather. Survey sites often have obstacles such as fences or silt curtains. There was consensus that certain terrestrial surveying tasks will likely always be suited to one type of technology over others. For example, habitat mapping seems likely to be far easier by a drone than by a ground-based robot.

Once we had considered what might be possible for robots to accomplish, lots of scenarios were brought up in which access by humans is challenging and opportunities for robots may exist. The discussion of drone versus surface-moving robot (both of which might be used in terrestrial habitats) came up several times, with drones often argued as being an easier way to access high sites or cross difficult terrain compared to a ground-based robot. Yet drones have limitations, including potential disturbance from noise, challenges of flying through a dense canopy and limited battery power due to the need for constant motion. In contrast, ground-based robots can remain still and silent between movements, conserving energy and potentially reducing disturbance.

Theme 2: why use robots when we have people?

There were some areas where it was argued that humans would always be needed; for example, a site walkover, consisting of a preliminary look at what important habitats and species are or could be present. An ecologist may conduct a habitat survey while also looking out for bird or reptile habitat, bat roosts or badger signs, with no pre-conceived ideas of what they might find. Although robots can be multi-functional, it was argued that they could not replace experience built up over a person's career.

Another major issue for robots is the identification of species or individuals. While AI is making big strides in species identification from images or sound, botanical identification necessitates 'hands-on' work (e.g. opening parts of the plant, using a hand lens to look at one specific element of a plant to distinguish between two similar species). These elements would require very fine motoric skills, although it was countered that a future robot could potentially use environmental DNA (eDNA) to identify a species in the field.

It was noted by a roboticist in the group that there is always a trade-off in robots between specialisation and the ability to perform general tasks. Tree-climbing robots were mentioned as an example. Such robots are often 'over-specialised', meaning they can do one role very well but would not adapt well to moving across the ground between trees, or perhaps to climbing built structures (Figure 2). Humans, with the correct training and kit, can both walk and climb. It was posited by one ecologist that there are two broad reasons for using robots instead of human surveyors: if it can do the job either (1) more efficiently (saving resources, money or time) or (2) more safely.

Figure 2. Treebot, a tree-climbing robot. This robot is highly specialised to climb trees but would struggle to adapt to other surfaces. Reproduced from Lam and Xu (2011) under Creative Commons licence CC BY 4.0.

Figure 3. A common autonomous sensor box platform. This robot is designed to collect a range of different data including vegetation characteristics, tree locations and invertebrate data. Reproduced from Noskov *et al*. (2023) under Creative Commons licence CC BY 4.0.

Doing the job better or more efficiently

Informing protected species survey and habitat management requires high-quality data. Humans are subject to fatigue and boredom, which can result in data quality changes over time, creating bias. Where the surveying includes a repetitive task, such as taking a sample at the same time each day, robots may be better suited to do it more frequently, for longer and more consistently, generating time series data. Examples discussed included collecting eDNA samples from across multiple ponds in an area, identification of bats and birds using sound and acoustic exposure mapping.

The ability of a robot to move may be particularly useful for acoustic monitoring where an array of locations is required, but conducted by one single moving device, rather than a human having to move a device around or deploy multiple devices. It was suggested that a terrestrial robot could act as a temporary ‘static’ recording device (e.g. bat detector, camera trap, passive acoustic monitor), then move between sampling locations, reducing need for ecologists to move/rotate devices, or reduce the number of devices needed. As one ecologist noted “this could open the door for more statistically robust grid and random sample approaches than the small number of selected points ecologists often have to rely on (particularly in consultancy) due to the trade-off between scientific robustness and pragmatism”.

It was envisaged that robots could be left on site to collect long-term data, in a way that human surveyors cannot, at least not without financial and well-being implications. Such a robot could be programmed to carry out a series of surveys at different times related to objectives for a site. One ecologist named this idea the “sleeping surveyor”, in that the robot could have pre-programmed sampling routine, but could also be remotely and temporarily redeployed *ad hoc* from its routine of monitoring to check something else on site. It was also discussed that robots might be able to perform multiple tasks at once (Figure 3). For example, it could carry out a primary task while also collecting incidental visual/acoustic data and thus pick up any species of interest. Alternatively, the same robot could carry out different primary tasks depending on the time of day; for example doing an acoustic bird survey during dawn and an acoustic bat survey at night.

Doing the job more safely

Human safety is a major issue in field surveys. Robots might be useful for surveying areas that are perhaps not so physically challenging, but not very safe to be in, such as highway verges or railway embankments. Tasks such as accessing sites high in trees take a lot of energy, effort and preparation (including extensive health and safety considerations and training). Bat survey guidelines require tree-based surveys, which aren't easy or cheap. Sometimes dead trees, or parts of trees that have fragile features, are left un-surveyed due to risk to human surveyors or to those features themselves. Robots might present an opportunity here. While not being able to fully replace humans, robots could be used for initial assessments of tree condition, which could then, if necessary, be followed by human inspection. Although cameras on poles can be used for this, they have limitations in terms of access for a complex structure. Similar issues may exist with other 'vertical terrestrial environments' such as viaducts, bridges or cliffs.

It was also argued that we know very little about the inside of animal burrows, dens, etc, and surveys tend to be destructive or of poor resolution (e.g. ground-penetrating radar). There may thus be an opportunity to deploy robots in such contexts, such as the WomBot, a small unpiloted tracked vehicle designed to enter and monitor wombat burrows in Australia (Ross *et al*. 2021). The same is true for parts of derelict buildings that cannot be accessed, and this aspect overlaps with safety considerations as discussed above. The inside of small cavities and crevices (including surveying of bat roosts) was also discussed as an area where there was clearly scope for the future for development of nano-/micro-robots, although it was noted by the roboticists that the computational demands on such systems are very high.

The safety of the animals being surveyed is not the only necessary consideration, but also the safety of the robot. Destruction or damage will have cost and data-quality implications. Static equipment, such as camera traps or acoustic monitors, is in general likely to be cheaper to replace than robots, so the ability to avoid theft or vandalism could be critical to both their effectiveness and adoption by ecologists. Camera traps and passive acoustic monitors may often be most important during nocturnal or crepuscular periods (e.g. for mammal survey and/or bird dawn chorus). Robots could potentially 'hide' by retreating to cover during daylight (or other non-operational) hours when risk of opportunistic theft or vandalism might be highest. Similarly, they might be able to move to avoid harsh weather or flooding. During the workshop, several factors that might harm a robot or its ability to complete its task were mentioned, such as badgers destroying robots perceived as a threat, or robots being covered in guano during a seabird survey which could hinder movement or cover sensing equipment.

Theme 3: will robots cause too much disturbance?

Despite some mixed views, there general was consensus that, in many contexts, robots have the potential to cause less disturbance to animals or habitats than human surveyors. Assessing disturbance is complicated by the fact that animals can habituate. For example, it was noted that while ecologists may consider groups such as bats as very prone to disturbance (reflected by our strict legislation), they are also found living in noisy railway tunnels or motorway bridges. Perhaps an adaptive robot could potentially 'learn' its limits of disturbance by monitoring responses to its own movements or sounds, adjusting accordingly. Nevertheless, it was argued that there may always be some tasks (such as endoscope surveys of bats) that may be too risky to entrust to robots, due to risk of injury/death, and may always require a licensed surveyor to supervise.

> **"Human safety is a major issue in field surveys. Robots might be useful for surveying areas that are perhaps not so physically challenging, but not very safe to be in, such as railway embankments."**

An interesting discussion centred around the fact that robots could be designed to deliberately disturb animals. For example, they could be operated in place of birds of prey which are used to deter birds from runways to reduce airstrike incidents or from crops to reduce economic damage. The use of AI in species recognition was also discussed several times and it was argued that while species recognition may be useful to locate protected species or identify habitats, it could also be used to identify invasive species.

Theme 4: what do ecologists and roboticists need from each other?

It was argued in the meeting that ecologists will gain most from roboticists (at least in the span of our careers) where there is a focus on developing affordable technologies that might become commercially available in several years, not decades. An example given came from bioacoustics: currently, a proportion of surveyors in the field are still using bat detectors that require manual identification, while advanced AI technology exists to do this task automatically. Yet costs/training/ability mean that it is often easier for an ecologist to stick to a known approach. It was posited that there is a middle ground, where technology is developed that makes incremental improvements that are of practical use for most ecologists in the field, and thus adopted, i.e. they tip the balance in the trade-off of investment of time and money vs 'just doing it the old way'. It was also argued that such smaller increments in technology would likely keep the cost down, making the use of robots more feasible for commercial adoption. Increasingly, ecologists are required to master technologies alongside traditional field skills, creating new challenges. An ecologist who manages a very large team suggested that the most useful robots in ecology would not require a deep specialism to deploy, but would be self-explanatory to use.

On the other hand, it was reflected by a roboticist that many of the ideas raised about types of robot, including functions such as automated species identification (at least across a broad array of taxa that equals many experienced human surveyors), moving in complex, cluttered or vertically challenging environments, and overcoming power constraints, are problems that may take years of development in both hardware and software to achieve in a commercially viable way. Nevertheless, we agreed that more dialogue between ecologists, about what type of data they collect (or want to collect) and the constraints they face, and roboticists, who may be able to find solutions, is likely to help find incremental developments. An example raised was a 'smart camera trap' that could function like a typical camera trap but have the ability to slightly change position or angle to get a better field of view in response to what it detected.

Conclusions

In conjunction with the workshop, the Centre for Conservation and Restoration Science has been undertaking a systematic review of robots used in ecological monitoring, which is demonstrating that terrestrial robotics is less advanced that marine robotics. We aim to identify the existing uses and potential opportunities for robots for terrestrial ecology, and thus areas where research and development (e.g. in power management, mobility, autonomy) are most needed. Robots and other remote sensing devices can collect large volumes of data, creating challenges in terms of management, storage and carbon costs. As an interdisciplinary team, it is clear that dialogue between ecologists and roboticists is critical to this, particularly if we want robots designed to meet the very specific needs of ecological monitoring (robots-*for*-ecology; Table 1) rather than adapting general robots for this purpose (robots-*in*-ecology).

The views expressed resulted in very productive knowledge exchange between ecological consultants, ecological researchers and roboticists.

The overarching sense was one of cautious optimism about robotics in ecology. Mirroring perhaps some of the widespread adoption and trialling of AI and machine learning in ecological surveying, it revealed that ecologists have many roboticist-inspiring ideas for how robots could be used to collect more and better data or reduce risk in human surveying. It looks like our industry will still need 'boots on the ground' for some time to come, but maybe if we start to identify and test incrementally more complex tasks that robots can achieve, particularly for repetitive jobs or jobs in poor working conditions that many ecologists don't like doing anyway, we may also start to see 'bots on the ground' in the span of our careers.

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