Application of the Internet of Things (IOT) to Animal Ecology

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SHORT COMMUNICATION

The application of the *Internet of Things* to animal ecology

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Abstract

For ecologists, understanding the reaction of animals to environmental changes is critical. Using networked sensor technology to measure wildlife and environmental parameters can provide accurate, real-time and comprehensive data for monitoring, research and conservation of wildlife. This paper reviews: (i) conventional detection technology; (ii) concepts and applications of the *Internet of Things* (IoT) in animal ecology; and (iii) the advantages and disadvantages of IoT. The current theoretical limits of IoT in animal ecology are also discussed. Although IoT offers a new direction in animal ecological research, it still needs to be further explored and developed as a theoretical system and applied to the appropriate scientific frameworks for understanding animal ecology.

Key words: animal detecting, environmental monitoring, Internet of Things, wireless sensor network

INTRODUCTION

Animal ecology is the science of the relationships between animals and their surrounding environment - both organic and inorganic. To determine what mechanisms result in adaptations of animals to the environment, parameters such as morphology, physiology, behavior, development and population dynamics, including interaction with predators and competitors, need to be assessed. There are many well-established methods and techniques applied in animal ecology, and recent advances have enabled novel research perspectives and opportunities for the discipline. We reviews some commonly used research methods for animal population ecology, and investigate the current and future application of the "Internet of Things" (IoT) technology in this field as well as its advantages and disadvantages.

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CONVENTIONAL DETECTION TECHNOLOGY IN ANIMAL ECOLOGY

The earliest method to measure the behavioral patterns of animals was by direct observation through field tracking and observing individuals and groups. This method is still the main approach to study many species, including diurnal vertebrates (Wilson & Delahay 2001). However, this approach may cause subjects to deviate from their natural behavior due to human disturbance, which can compromise the resulting data (Harris & Burnham 2002).

With the development of radio telemetry, the ecology and behavior of difficult-to-track vertebrates could be more reliably recorded, including wide-ranging marine vertebrates such as turtles (Dizon & Balazs 1982) and rare, secretive nocturnal predators such as leopard cats (Grassman *et al*. 2005). Radio tracking devices incorporating global positioning systems (GPS) can record animal activity patterns at much larger spatial scales: for example, for migratory birds (Guo *et al*. 2015) and mammals. This new technology has revealed in more detail the population dynamics and reproductive biology of several vertebrate species. The use of GPS technology has been reviewed previously for some mammals and birds (Wu *et al*. 2008; Miller *et al*. 2010), with emphasis on the limitations of such devices. For example, data recorders are usually only effective for 1 to 3 years due to battery life, radio signals are sometimes unreliable, and units need to be recovered for data access, which may increase the potential for accidental injury in some species.

The movements and populations of animals, mainly vertebrates, can be recorded without intrusion using traditional tracking methods. For example, the sizes, and the sex and age make-ups of ungulate populations (Jiang *et al*. 2001) and the habitat preferences of wolves (Li *et al*. 1999, 2005; Liu *et al*. 2002; Zhang *et al*. 2010) can be estimated by footprints left in snow. Counting dung patches is an effective method of estimating forest musk deer numbers (Wei *et al.* 1995). However, such methods are unlikely to accurately record individual behavior, and because quantitative predictions of populations subsequently need to be made by extrapolation, the accuracy of the data may be affected.

In recent years, several new methods that avoid direct human contact with animal subjects have been developed for measuring and recording ecological data for animals in the field. One such method, which is being increasingly applied, is the use of static infra-red cameras to record the presence and movement of cryptic, nocturnal vertebrates. For example, this method has been used to record the abundance of large cats such as jaguars (*Panthera oncas*) (Trolle & Kéry 2005; Heilbrun *et al*. 2006) and tigers (*Panthera tigris*) (Carbone *et al*. 2001), ungulates (Jia *et al*. 2014) and other species of mammals (Lu *et al*. 2005; Rovero & Marshall 2009). The use of infra-red cameras to monitor and investigate wildlife has become popular in China (Xiao *et al.* 2014).

Radio frequency identification (RFID) has been developed for tracking and marking individual animals (Huang & Ku 2009). RFID is a wireless communication technology useful for precisely identifying objects by using radio frequency waves to transfer identifying information between tagged objects and readers. Each RFID has a unique identity code, also known as RFID tag, which can be attached to an animal as its "ID card." RFID tags are often classified as being either active or passive. Active RFID tags have an internal power source and emit a radio signal that can be detected at a distance; they tend to be used for short time periods before removal. Passive RFID tags do not emit a signal but require a powered detection device near the subject animal for monitoring and can be used throughout an animal's life. RFID tagging can be applied in tracking individuals to study population diffusion, individual movements in space and over time, and to reveal other important information on population ecology (Schooley *et al.* 1993; Harper & Batzli 1996; Rogers *et al.* 2002). This technique has been widely used in captive animals in the management of their reproduction and communication, and these new detection technologies are likely to make the study of wild animals easier.

However, the use of RFID also usually requires direct observation and monitoring, which is time-consuming and labor-intensive, with multiple subjects necessary to answer most scientific questions on animal ecology. Other problems with the use of RFIDs have been reported. For example, when RFID tags have been used on burrowing animals, electromagnetic signals emitted by RFID units have been weak and difficult to detect. The electromagnetic waves suffer from severe attenuation due to soil and moisture when the conventional radio-tagged methods are used to locate the burrowing animals. To solve this problem, researchers have used magnetic induction wireless positioning, applying automatic sensor array equipment, which is unaffected by water or soil. This equipment can track burrowing mammals, such as the European badger (*Meles meles*), automatically to obtain the position of each individual in a sett at a particular point in time. These data can then be used to produce a graphic visualization of the movements of all individuals within a sett superimposed on a diagram of the tunnel network (Markham *et al*. 2010). The use of IoT in animal ecology can be based on such technologies.

THE CONCEPT AND BASIC FRAMEWORK OF THE *INTERNET OF THINGS* APPLIED IN ANIMAL ECOLOGY

In 2005, the International Telecommunications Union (ITU) formally presented the concept of the IoT. The IoT incorporates all kinds of sensing networks, such as RFID devices, GPS technology and laser scanners, which are connected to the Internet to form a supernetwork. People can manage their working and home lives more efficiently and dynamically through the IoT, increase productivity, and improve the relationship between humans and nature.

The IoT is a vast network, formed by combining objects, processes and information with the Internet. The objects and the processes, which need to be monitored, connect or interact during real time, and the information conveyed includes sound, light, heat, electrical, mechanical, chemical, biological and location information that can be gathered by a variety of sensing devices. These include wireless sensor networks (WSNs), RFID technology, GPS technology, infrared sensors, laser scanners, gas sensors and other equipment and technologies (He *et al*. 2006; Werner-Allen *et al*. 2006; Liu *et al*. 2011; Mao *et al*. 2012). Typically, IoT architecture is classified into 4 layers: (i) the perceived identification layer; (ii) the network construct layer; (iii) the management service layer; and (iv) the integrated application layer (Thiagarajan 2009). Hence, IoT is a network formed from a variety of sensors, which are used as basic detection nodes. The subjects of detection may be a variety of inanimate objects, those associated with living organisms and environmental parameters. The central computing system processes the data sent from the detectors, which are then fed to the effectors or managers for appropriate processing depending on the application (Dargie & Poellabauer 2010).

In some circumstances, IoT has thus been fully applied to the ecology of certain animal species. Because of different research goals and various means of detection, methods to process the data retrieved by sensors, and interaction between those data, the detectors and the effectors, will differ. IoT systems involve the simultaneous use of multiple information engineering technologies applied to ecological principles. These complex networks can be divided into different multi-stage feedback paths (as shown in Fig. 1). Briefly, they are processes incorporating signal detection, data processing, and feedback. The physical or chemical data can be obtained by corresponding detectors in the process of detecting signals, and then transferred to the server and processed. Finally, researchers and managers can make judgments as to how best to obtain the optimal data to achieve specific goals. For hardware configuration, the most important components are the detector nodes and the network supporting data transmission. Researchers need to set up these nodes according to specific environmental conditions based on the known ecological information about the animals to be studied. In accordance with the physiology of the animals to be studied, researchers should use appropriate detectors, such as acoustic, optical or chemical detectors, to record and/or track the target animals. Researchers should take into account the known behavior and/or ecology of the target species to decide the optimal number and the layout of detector nodes to be used.

Poter *et al*. (2005) discuss how to arrange an IoT network, according to specific research goals, data type and other conditions. The cost of the individual nodes has fallen with the rapid development of data transmission and detector technologies. The transmission of much data over a relatively short time no longer creates a bottleneck within a network deployment due to the development of compression and transmission technologies. Currently, various embeddable detectors can be used as detection nodes in an IoT network (International Telecommunication Union ITU 2005). A network can transfer real-time data from each node and continuously record various environmental parameters.

THE APPLICATION OF THE *INTERNET OF THINGS* TO ANIMAL ECOLOGY

Currently, various forms of emerging IoT technology have been applied to animal ecology research. Various species of terrestrial and aquatic vertebrates, for instance, have been identified through computer-assisted technology. For example, a database of individual Grevy's Zebra (*Equus grevyi*) stripe-patterns has been established, based on "noisy" images obtained from a locality favored by Grevy's Zebras. The images of a new, previously unknown animal can be automatically compared with those already in the database to determine whether an animal is a Grevy's Zebra or another species (Lahiri *et al*. 2011).

The "RatPack" project at Rheinisch-Westfaelische Technische Hochschule Aachen (RWTH Aachen) aims to monitor the behavior and movements of underground rodents using wireless sensor nodes to perform sound analysis, position calculation and terrain rendering, and provides a new method for studying rodent behavior in the natural environment (Bitsch *et al*. 2010). Researchers at Antilles and Guyana University (UAG) have proposed a method to identify the cooperative behavior of birds by recording the movements and songs of individuals, using an acoustic sensor array comprised of a series of wireless microphones. Different bird spe-

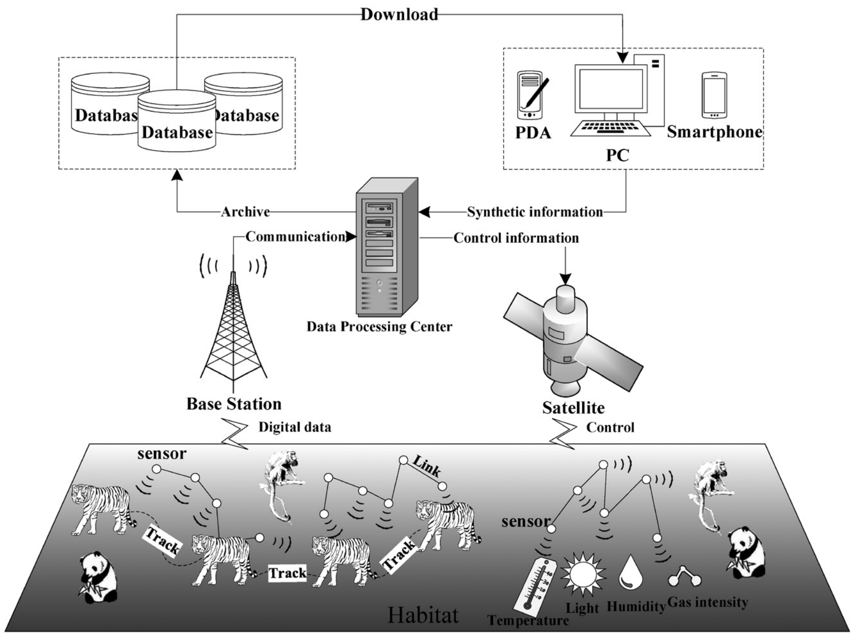

Figure 1 The wireless sensor network in animal and environmental monitoring.

cies have been automatically identified using a wireless acoustic sensor array (Chen *et al*. 2006).

Acoustic sensors have also aided researchers in the field in recording the sound activities of individual marmots, by confirming the position of individuals making alarm calls via a network of wireless acoustic recorders (Ali *et al*. 2009). Wireless sensor network technology has also been used to monitor large animal populations over a wide area. This technique has provided high-resolution data for monitoring seabirds that nest in the UK (Naumowicz *et al*. 2008), and for monitoring and counting the relative numbers of native frogs to invasive cane toads (*Bufo marinus*) in northern Australia (Hu *et al*. 2009). All the work mentioned has used various types of physical detectors to study activity patterns, and to identity individual animals after the detected signal was processed in an Internet-connected data processing center.

These network nodes can also detect environmental data simultaneously to data recorded from the target animal. Furthermore, the impact of environmental changes on animal behavior and ecology can be assessed from these automatically recorded data. For example, underwater sensor network platforms have been used for long-term monitoring of coral reefs and fisheries, using sensor networks that include both static and underwater mobile sensor nodes. These are capable of recording images, water temperature and pressure, and other information. Similar systems can also be used for still-water, river and open-ocean data collection (Vasilescu *et al*. 2005). IoT can also be used as a wildlife management tool. For example, in zoos, wireless video nodes can be installed to form a visual sensor network, so animals' movements and behavior can be monitored remotely. Vibrotactile collars connected to a sensory network can also be used for behavioral management of zoo mammals. These integrated systems provide a new interactive way for humans to manage wildlife (Fahlquist *et al*. 2010). This zoo example can be considered a full application of IoT, in that it covers most IoT basic elements, including the identification of individuals, a network of detectors, and several platforms for information feedback and processing.

Two recent systematic studies in China exemplify pioneering work in the field of IoT. The Green Orbs project has been conducted at some major universities, with a collaborative project involving the Hong Kong University of Science and Technology, Tsinghua University, Xi'an Jiaotong University, Zhejiang Forestry University, Zhejiang University, University of Illinois and Nanyang Technological University. This involved wireless sensor networks on the Tianmu Mountains in Lin'an Zhejiang to monitor carbon missions, plant life and wildlife. Much data has been recorded for temperature, humidity, light and carbon dioxide concentrations, and other parameters for forest monitoring, fire risk assessment and wildlife rescue. However, this work only partly monitors the environmental parameters of wildlife habitat (Liu *et al.* 2013). Northwest University in Xi'an, China has applied IoT in the wildlife reserve inhabited by endangered golden snub-nosed monkeys (*Rhinopithecus roxellana*) in the Qinling Mountains. Aimed at identifying the particular requirements for wildlife protection, researchers used limited IoT resources to monitor the activities of monkeys and to collect environmental data. These data were transmitted to a control center via Quality of Service, which is a network security mechanism used to address issues such as network latency and blocking. Finally, this work has added to information needed for the protection of *R. roxellana* at the Qinling Mountains (Liu *et al*. 2011).

ADVANTAGES AND DISADVANTAGES OF INTERNET OF THINGS FOR ANIMAL ECOLOGY RESEARCH

The IoT is considered an emerging industry, and has considerable potential for development. IoT has many technological advantages for ecological research and the monitoring of wild animals. First, IoT can acquire data continuously, and also adjust the frequency of data collection through remote adjustment of the sensors, which effectively increase the service time of power supplies. Second, IoT can remotely monitor animals and their environment, and, thus, exclude any effects of human interference to record data more objectively. Additionally, a network can function for a long period of time (as opposed to humans) and provide interactive services such as reminders and alerts for users by setting of thresholds on the back-end server by the operator. Finally, after installing the management devices, IoT can implement the interaction with the user under the control of the network client, and improve the efficiency of animal monitoring and management.

There are some problems in applying IoT, including issues with the short life of batteries, incompatible sensor components and transferring data, particularly large video files (Tan *et al*. 2010). However, such disadvantages will be improved with the development of the IT industry: for example, with sensors using new long-life solar energy drive batteries, developing uniform integrated sensor components, and quality of service techniques making the transfer of data more stable (Amardeo & Sarma 2009). Further IoT application in animal ecology research will require not only the input of IT professionals, but also the design ideas of animal ecologists.

CONCLUSION AND RECOMMENDATION

The application of IoT is a new direction for ecological research. However, except for the general frameworks mentioned above, we still regard IoT as a theoretical system and a "work in progress" requiring further development for its full application to research in animal ecology. Firstly, we recommend that potential users carefully consider sensor type to be use and overall design of the frameworks for each species-specific project. Animals in different habitats will require different sensor configurations, power supplies and data transfer strategies. For example, the optimal type and density of the sensor will differ for grasslands or forests. Secondly, users need to design and optimize the specific strategies for energy output, data storage and battery model in order to maximise battery life according to their specific research goals and the funds available for a given project. Finally, users should design a strategy for data transfer and storage, and prioritize the most important parameters to measure. Users need to ensure that their IoT data can be transferred and saved safely and effectively under a limited network bandwidth. Ecologists should make full use of the advantages of this advanced technology. Using IoT in diverse habitats will present challenges to animal ecologists, however it will provide novel opportunities to study animals in their natural habitat and lead to improvements as this exciting new technology evolves.

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