Proposal for capturing, quantifying and relating motion and movement based collective animal behavior to dynamic environmental variables: the case of reindeer and wind turbine operations

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Abstract

Effective quantitative methods are needed to evaluate the effects of infrastructure developments on wildlife and biodiversity. To this extent, this paper proposes a real-time, large-scale, cost-effective, fine-grained data collection and analysis framework and system that uses Internet of Things (IoT) technologies and geoinformatics-based analyses to objectively quantify and monitor motion and movement based collective animal behavior in context. The frameworks is planned to be developed and applied to evaluate how reindeer react to the presence of wind power infrastructure and its operations. The framework has three main components as follows. The *IoT Based Motion and Movement Data Collection* component meets application requirements through smart-sampling, data compression and preprocessing via edge computing and a crowd positioning approach. The *Motion and Movement Based Collective Behavior Analysis* component uses generative mixture modeling and cluster analysis to monitor the motion and movement patterns and the implied high level behaviors / activities in space and time. Finally, the *Spatio-temporal Contextual Analysis* component 1) uses remote sensing and traditional GIS analyses to measure the dynamically changing distributions of resources and obstacles in the environment, 2) correlates the intensities of and changes in animal movement and behavior with the changing resources and obstacles in space and time, and 3) evaluates the access of the animals to the resources using recent corridor analysis techniques. It is conjectured that the knowledge generated by the planed application of the proposed framework will enable discussions and decisions that lead to wind power infrastructure developments and operations that are economically, ecologically and socially sustainable.

1 Introduction

Ethology or behavioral ecology investigates the role of behavior into the survival of a population or species. For a wide variety of animals, including mammals, reptiles and amphibians, fish and invertebrates, henceforth collectively referred to as herd-, flock-, or gregarious animals, an important and arguably defining part of this behavior includes that a group / population of animals of the same species tend to congregate into- and collectively move together as a group (Sumpter, 2010).

Collective animal behavior and specifically grouping and collective movement provide these animals with shelter from the elements of nature and predators, ways to locate food and other resources, ways to find optimal migration paths, and the necessary environment for basic social and reproductive functions (Sumpter, 2006). The movement patterns that these groups create 1) are neither entirely regular, nor entirely random, 2) are both formed by limited local knowledge, interactions and simple rules (e.g., "(i) move away from very nearby neighbours; (ii) adopt the same direction as those that are close by and (iii) avoid becoming isolated" (Sumpter, 2006)) as well as features of the environment (Dodge, Bohrer, Weinzierl, Davidson, Kays, Douglas, Cruz, Han, Brandes, and Wikelski, 2013; Avgar, Mosser, Brown, and Fryxell, 2013; Ahearn, Dodge, Simcharoen, Xavier, and Smith, 2017) and 3) exhibit complexity that arises form self-organization (Sumpter, 2006). Developing systems and methods for capturing, quantifying and relating these collective animal behaviors (in particular collective movement) to the environment is the aim of the proposed study.

While wind energy is an important renewable source of energy, wind power infrastructure has potential negative effects on wildlife and biodiversity. For this reason, the Swedish Environmental Protection Agency and the Swedish Energy Agency have, since 2005, supported projects to investigate the effects of wind power generation on reindeer, both wild and domesticated, which are part of the livelihood and culture of the Sami people, Sweden's native population.

A large body of knowledge has been generated. Strand, Colman, Eftestøl, Sandström, Skarin, and Thomassen (2017) summarize the results of eleven studies and try to explain the differences in results as follows. Reindeer generally try to avoid roads and roads limit the natural movement patterns of reindeer. The effect of power lines is less studied, but negative effects have been documented especially in the construction phase. Some studies have documented that wind turbines and rotors are also avoided by reindeer by a margin of 3-5 km, while other studies could not confirm such patterns. It is believed that the differences in the studies is largely influenced by the shortcomings of the applied study methods.

In particular, previous studies mostly used traditional techniques: 1) visual inspection of individual and small groups of reindeer with binoculars and estimating the position of the animals with the help of a compass and distance measuring equipment and 2) mapping of animal droppings. In recent years, the ocular methods were augmented with the use of a handful of a GPS receivers, but due to battery and mobile communication limitations, the measurements were extremely sparse, i.e., maximum one measurement per hour with possibly several days of gaps, which introduced large uncertainties and severely limited the subsequent analysis. In summary, the methods used so far were costly, subjective and error-prone and the results had a high uncertainty.

To address these shortcoming this paper proposes a measurement and analytical framework that uses Internet of Things (IoT) technologies as well as geoinformatics-based analyses to objectively quantify and monitor motion and movement based collective animal behavior in context. The framework is planned to be applied to study how reindeer react to the presence of wind power infrastructure and its operations. The purpose of the submission of the paper is to spark discussions in and receive feedback from the computation movement analysis research community.

The rest of this paper is organized as follows. Section 2 describes the IoT based motion and movement data collection. Section 3 describes the general approach for the motion, movement and activity analysis of flocks. Section 4 described geominformatics-based analyses that capture dynamically changing resources and obstacles in the natural and built environment and relate these to the movement of the flock. Finally, Section 5 concludes.

2 IoT Based Motion and Movement Data Collection

According to Wikipedia, "the Internet of Things (IoT) is the network of physical devices / objects [...] embedded with electronics, software, sensors, actuators, and connectivity which enables these objects to connect and exchange data [about their environment and context]." These devices can 1) measure various aspects of their environment / context including their position, motion, orientation, and rotation, 2) communicate in real-time and 3) perform simpler computations. These capabilities make IoT a booming area in industry and research and introduce a paradigm shift in applications, including animal behavior- and environmental analysis.

The proposed framework utilizes these capabilities to create an effective, large-scale, real-time tracking system for flocks as follows. To overcome the problems of limited mobile network coverage in the native environment of the animals, the framework will utilize the LoRa (Long Range, low power) wireless communication platform consisting a few relatively inexpensive ($1,500) base stations that serve as gateways to the Internet and can communicate with the IoT devices within range. To allow data collection through extended periods, which is required by the application—reindeer are gathered only once a year, the IoT devices will implement battery-efficient tracking techniques that duty cycle the expensive positioning measurements only for periods when the inexpensive motion sensors (i.e., accelerometer) sense motion that co-occurs with significant movement (Prelipcean, Gidófalvi, and Susilo, 2014). To reduce the amount of communication between the base stations and the IoT devices, the devices will compress both the motion and movement data. In particular, the motion data will be compressed by detecting peaks in the sensor readings and computing window-based statistics over the detected peaks (Prelipcean et al., 2014; Prelipcean, Gidófalvi, and Susilo, 2016) and the movement data will be compressed using an on-line variant of the Douglas–Peucker algorithm. Finally, to allow the collection of motion and movement data for large flocks at a low cost, the tracking system will employ the concept of crowd positioning, whereby a large number of inexpensive and battery-efficient devices will opportunistically communicate with their nearby location-aware peers using short-range radio communication (e.g., Bluetooth Low Energy (BLE)) and indirectly upload their compressed motion data along with the position of their location-aware peer.

The proposed hardware for the IoT Based Motion and Movement Data Collection component are:

- MultiConnect Conduit IP67 LoRa gateways / base stations with antennas with a 15-30 km radius range depending on placement, and

- Collar mounted Sodaq-ONE based animal tracker devices containing a small, energy-efficient ARM processor on a micro controller unit, a LoRa transceiver, both a low-power accelerometer and a three-axis linear accelerometer, a 10Hz GPS with fast fix acquisition time, and a BLE unit for peer-to-peer communication, all of which is powered by a 1-10Ah battery.

Provided these hardware components and the above described sensor network architecture and methods, the IoT Based Motion and Movement Data Collection component is estimated to reach the following sensing capabilities. The temporal resolutions for GPS-equipped trackers when the animal is on the move will be 1-5 seconds. The temporal resolution for accelerometer measurements are planed at 5-10 Hz that has proven to be effective for detecting and characterizing human motion (i.e., step counting and detection of walking) and for motion-activated adaptive GPS sampling. The temporal resolution for BLE measurement attempts for crowd positioning is planned between 1 and 0.2 Hz, which can be implemented in an energy- and cost-effective way using broadcast based proximity sensing, but the actual achieved temporal resolution of crowd positioning measurements is a function of the movement dynamics of the flock and will be investigated the proposed study. Using these settings it is estimated that the sensor network will be able to collect continuous motion and movement data for 10% of 3000 reindeer (i.e., 300 trackers) on a grazing area of 2500 hectare (i.e., approx. seven base stations) for a duration of a year at a cost of $30,000.

3 Motion and Movement Based Collective Behavior Analysis

With the widespread adoption of low-cost sensors, since the early 2000s, computational movement (and activity)- analysis and modeling became a hot research topic. Dodge, Weibel, and Lautenschütz (2008) present a taxonomy of movement of patterns dividing patterns into behavioral and generic patterns. While generic patterns mainly relate to regularities in the physical movement of an individual or a collection of objects (e.g., animals, people, vehicles), behavioral patterns relate to higher level concepts in behavior (e.g., flocking, playing, grazing, resting, etc.) and often involve the relative movement and motion of the objects. Laube, van Kreveld, and Imfeld (2005) present a computational framework for identifying relevant behavioral patterns like “flocking”, “tracking”, “leadership-follow”, “convergence” and “encounter” based on relative movement.

The proposed *Motion and Movement Based Collective Behavior Analysis* component will extend this computational framework of relative movement with relative motion and combine it with prior research of the author (Prelipcean et al., 2014, 2016; Prelipcean, Gidófalvi, and Susilo, 2017) on trajectory and mobility data mining and modeling techniques. In particular, geometric-, geographic-, and relative movement and motion features will be derived from temporal windows of movement (GPS) and motion (accelerometer) measurements / data. Subsequently, parameters of a generative mixture model will be estimated using the expectation-maximization algorithm to model the distribution of the data and to effectively label individual animal- or flock motion and movement as “normal” or “unusual” by thresholding on the likelihood of the data given the maximum-likelihood model parameters. Subsequently, cluster analysis techniques combined with expert knowledge will be applied to associate high level behaviors / activities (e.g., “grazing”, “resting”, “flocking” etc.) with particular data clusters. Changes in the characteristics and amount of movement and these high level behaviors will be monitored in space and time.

4 Spatio-temporal Contextual Analysis

To study the effects in context, the proposed framework quantifies the effects of and the access to dynamically changing resources in the natural environment in the presence dynamically changing obstacles in the build environment as follows. First, remote sensing technologies will be applied on big, multi-temporal and multispectral Earth Observation data cubes to quantify and monitor changes in vegetation- and snow cover. Second, noise will be studied with the help of a few, inexpensive noise and wind speed and direction sensors placed in the terrain. Time-varying measurements will be analyzed to provide a picture of the distribution of sound intensities around the windmills. The results will be improved using line-of-sight analysis and high-resolution elevation data. Third, the so obtained measurements about the natural and built environment will be classified as either resource or obstacles. Traditional techniques from geostatistics will be used to correlate the intensities of and changes in animal movement and behavior with the dynamically changing resources and obstacles in space and time. The study will also investigate the option of quantifying the correlation by directly linking raw motion and movement measurements and time-varying environmental variables from remote sensing products and visibility- and noise analysis via the publicly available environmental-data automated track annotation (Env-DATA) system (Dodge et al., 2013). Finally, as the loss and fragmentation of wildlife habitat has been long recognized as a major threat to biological diversity in general (Fahrig, 2003), a recent corridor analysis method (Shirabe, 2016) will be applied to evaluate the reindeer's access to its natural environment and food with and without the presence of obstacles (i.e., windmills and related support infrastructure and operations).

5 Conclusions

This paper outlined a real-time, large-scale, cost-effective, fine-grained data collection and analysis framework and system that uses Internet of Things (IoT) technologies and geoinformatics-based analyses to objectively quantify and monitor flock movement in context. The frameworks is planned to be developed and applied to evaluate how reindeer react to the presence of wind power infrastructure and its operations. The framework has three main components as follows. The *IoT Based Motion and Movement Data Collection* component meets application requirements through smart-sampling, data compression and preprocessing via edge computing and a crowd positioning approach. The *Motion and Movement Based Collective Behavior Analysis* component uses generative mixture modeling and cluster analysis to monitor the motion and movement patterns and the implied high level behaviors / activities in space and time. Finally, the *Spatio-temporal Contextual Analysis* component 1) uses remote sensing and traditional GIS analyses to measure the dynamically changing distributions of resources and obstacles in the environment, 2) correlates the intensities of and changes in animal movement and behavior with the changing resources and obstacles in space and time, and 3) evaluates the access of the animals to the resource using recent corridor analysis techniques. It is conjectured that the knowledge generated by the planed application of the proposed framework will enable discussions and decisions that lead to wind power infrastructure developments and operations that are economically, ecologically and socially sustainable

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