Opportunistic Data Exchange Algorithm for Animal Wearable Device Through Active Behavior Against External Stimuli

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Abstract. This paper proposes a method of communication wake control for encounters between three or more users of animal wearable communication devices when threatening behavior against an external stimulus is detected. Specifically, it identifies an encounter of three or more contacts using an acceleration sensor attached to an animal, and uses this as a trigger to wake the communication device to transmit and receive data between the devices. In order to evaluate this algorithm, evaluation experiments were conducted using four standard poodles. With the cooperation of veterinary researchers, we established conditions where strangers with cameras passed immediately in front of the dogs' run, in order to provide the threatening behavior used to trigger communication wake control.

Keywords: Animal wearable · Behavior · Animal-Computer Interaction

1 Introduction

The concept of humans and animals wearing sensors to enable the monitoring of their behaviors and the surrounding environment was introduced in the early stages of sensor network research. However, when studying wild animals, there are very limited opportunities to recharge sensor batteries. In order to acquire sensor information, an animal's device must contact a sink node that eventually connects to an external network, and the frequency of these contacts is low. It is therefore crucial to design sensor nodes with longer lifetimes and lower power usage.

More specifically, communication between wireless sensor nodes requires 100 times more power consumption than other operations [1]. Terrestrial mammals inhabiting forests are known to behave differently when they encounter other animals, compared to how they act in other situations [2].

When they encounter a different animal (which can be seen as threatening behavior against external stimulus), the probability is high that the sensor nodes worn by the

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animals are within each other's communication radius. Therefore, by activating the communication capabilities of a sensor node only when numerous animals are present (and putting the sensor node into a sleep state otherwise), it is possible to substantially prolong the lifetime of a sensor node.

This paper discusses the design, development and evaluation of a system to tackle this issue. Firstly, a new experimental system is designed based on observation methodologies in related studies. In addition, the spatial-temporal process of the nonhuman-centric interactions of users is evaluated using quantitative content analysis. Finally, on the basis of the experimental results, the overall findings are discussed, including a description of the possible applications of the system. The remainder of this paper is structured as follows. Section 2 describes the background to this study; Sect. 3 presents the proposed method; Sect. 4 gives details of the evaluation; Sect. 5 presents a detailed discussion; Sect. 6 summarizes directions for future research; and Sect. 7 offers conclusions.

2 Background

2.1 Technical Limitations on Animal Wearable Interfaces

The ecological monitoring of wild animals via ubiquitous sensor networks and mobile phones has already been realized in locations close to urban areas [3] (i.e. close to human societies); however, in wildlife habitats, power and information infrastructure networks are severely limited. More specifically, the profitability of infrastructure services is too low in areas where the number of users is extremely small, for example within the habitats of most wildlife. Furthermore, when setting up a ubiquitous sensor network, a great deal of effort is required in terms of coordinating with national parks and owners, administrative stakeholders, and other stakeholders. In addition, sensors installed outdoors incur very high installation, operational, and environmental costs. Given these limitations, wearable sensors for wildlife are attracting increased research attention.

To retrieve records acquired via sensors, we must recapture these animals (Fig. 1(a)) or use a wearable telemetry transmitter. The habitat within which wild animals can be recaptured and the telecommunication range for telemetry are both very limited, making it difficult to expand the scope of surveys and studies.

When targeting endangered species in Japan, the lifespan for the continuous operation of a compact and lightweight sensor for an animal is typically two years. The weight of the wearable device is limited to approximately 2–5% of the weight of the target animal [4]. Given that many target animals are small-sized terrestrial mammals that are light in weight, it is difficult to install and operate inertial navigation recording devices and the like, as illustrated in Fig. 1(b).

Furthermore, accurate time and position information cannot be expected from the records obtained from the wearable sensor nodes of wild animals. Given the weight limit restrictions, these do not contain an internal clock or an inertial navigation recording device. Satellite positioning and radio clock signals also face difficulties within forests [4], as illustrated in Fig. 1(c).

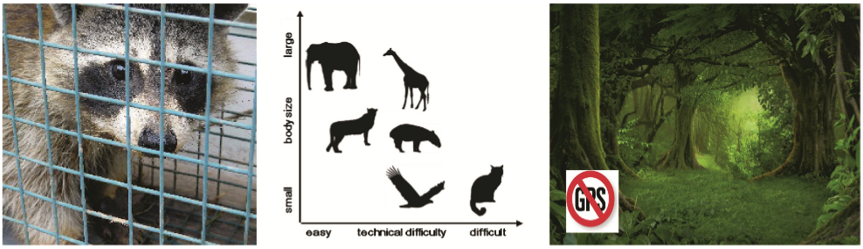

Fig. 1. (a) A wild animal captured in a trap; (b) a diagram showing the relationship between body size and technical difficulty; and (c) illustration that within a forest, GPS and mobile signals typically do not work.

In view of the above, we need a system that minimizes cost and maximizes efficiency in terms of acquiring spatial information, in order to conduct extensive and long-term wildlife surveys in habitats where there are minimal power supply and information infrastructures. There are three key problems here, and it is necessary to simultaneously satisfy all of the conditions summarized below:

- Coverage problem: Wearable sensors are restricted to physically recapturable individuals
- Operational time problem: Wearable sensors are restricted in terms of their operational period of time, since the weight of the wearable device needs to be limited to 2–5% of the animal's body weight
- Reliability problem: Satellite signals face major difficulties within various habitat topographies; thus, there is the problem of obtaining accurate location information for the acquired data.

Our proposal for realizing much longer lifetimes and power savings in sensor nodes by leveraging the ecological interactions of multiple wild animals is, to our knowledge, the first attempt at such an endeavor, and is an innovative system involving HCI. An illustration of this system is given in Fig. 2.

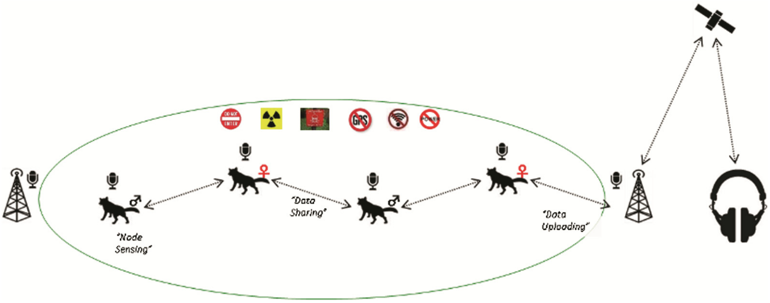

Fig. 2. Proposed sensing system/concept

2.2 Summary of Previous Research

In previous research, as illustrated in Fig. 3, a mechanism to realize telecommunication between two individuals was proposed involving the detection of an encounter by an algorithm using synthesized acceleration, and then triggering the wake control of the telecommunication device. The results show that telecommunication is possible with a probability of about 70% using the proposed algorithm [5]. In the proposed algorithm, the authors focus on two thresholds, meaning a time frame of between one and 10 s for pause judgment, and a threshold value of synthesized acceleration (0.2 G) for motion and pause judgment. However, we regard that it is not considered enough that their thresholds are optimized to each specific animal.

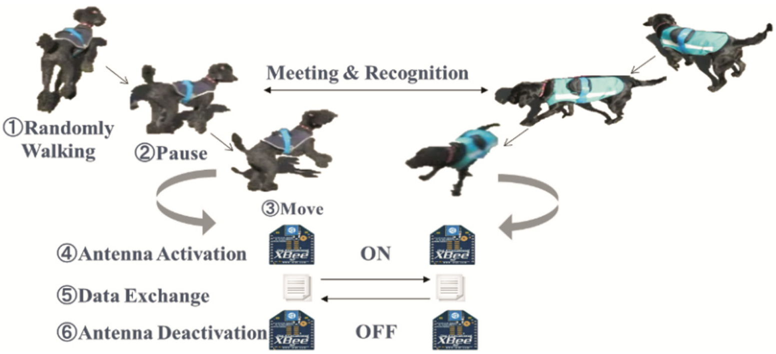

Fig. 3. Animal-to-animal data sharing between two individuals

The reason for this is that these thresholds vary depending on the conditions of the encounter with other animals, and the optimal threshold may differ depending on the species, the individual's physique, age, gender, personality and so on. Indeed, as discussed in previous research [8], the frequency of waking of the communication device varies depending on individual differences even for four individuals. In particular, there is a correlation between body height and sampling rate, and it is necessary to optimize the judgment threshold on the basis of the body height of each individual.

However, it is difficult to optimize the threshold according to body height in a genuinely wild environment, and it is not sufficient to consider only this element. Since it is necessary to determine the body height of each individual in advance, an increase in the number of individuals increases the preparatory labor, and the level of difficulty for local workers also increases, making this impractical. In encounters between individuals, there is also a difference between characteristic quantities of habitual behaviors in encounters with threats and herds of flocks, and existing studies so far have used no concrete definition for encounters between two individuals; it cannot therefore be said that this method has been sufficiently examined.

Since equipment is worn over several years, it is also necessary to consider changes in habitual behavior due to the growth of individuals, and it is necessary to set thresholds corresponding to time-series changes. Thus, dynamic algorithms reflecting these spatial and time-series changes are required.

3 Proposed Method

3.1 Detection Algorithm for Threatening Behavior Against External Stimulus

This paper proposes an algorithm optimization for the wake control of communication equipment in the time of a threatening encounter from the characteristic quantity of synthesized acceleration, as shown in Fig. 4. This algorithm is a preparation stage for a dynamic algorithm corresponding to spatial and time-series changes.

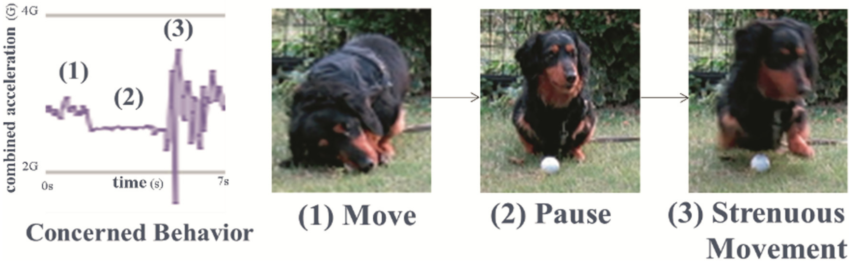

Fig. 4. Threatening behavior against external stimulus (single individual)

We will propose a method for algorithm optimization that improves the accuracy of waking of communication equipment by accurately determining both commonly seen and threatening behavior, and responding to chronological changes in the future work.

The proposed algorithm is as follows:

$$\begin{gathered} if\,(\Delta G > G') \\ \{Call\,for\,pause\colon 0.1\,s < t < 1.0\,s\} \end{gathered} \tag{1}$$

Where G' is a threshold value for judging threatening behavior. A mechanism for judging the time of intimidating behavior is added to the existing algorithm from the synthesized acceleration, acquired at a frequency of 20 Hz.

When judging threatening behavior using G', the algorithm transitions to a threatening behavior algorithm. In this second algorithm, $G = 0.2$, which is the same threshold used in the motion and pause judgment of the existing algorithm.

The rest time is set to $0.1\,\text{s} < t < 1.0\,\text{s}$, which means that the judgment interval related to the rest time is set to a tenth of the time of that used in the existing algorithm. Operation during threatening behavior is fierce compared with the commonly seen behavior and it is necessary to optimize the sampling rate according to its operation. In order to clearly separate the sampling rate from the commonly seen behavior, this is set to a tenth of the time.

4 Evaluation

4.1 Experiment

In order to evaluate this algorithm, four evaluation experiments were conducted using the four standard poodles shown in Fig. 5. In order to acquire accurate data during threatening behavior, we carried out an evaluation experiment in the outdoor dog run shown in Fig. 6, using acceleration sensors (MSR145 data logger) supplied by MSR Electronics. The dogs were free to move around without restraint. With the cooperation of veterinary researchers, we set up a situation where strangers passed immediately in front of the dogs' run, in order to provide the threatening behavior used to trigger waking of the communication equipment between two individuals. Evaluation experiments lasting 20 s each were carried out twice, and video recordings were made to evaluate the synthetic acceleration data and habit behavior. Sampling rate of MSR145 data logger in this experiment was 20 Hz as well as previous research [8].

1.KURT 2.KARL 3.JASMINE 4.NIKO

No.	Name	Dog Breed	Age (years)	Type	Weight (kg)	Height (cm)
1	KURT	Standard Poodle	3	Male	24	65
2	KARL	Standard Poodle	3	Male	22	63
3	JASMINE	Standard Poodle	9	Female	23	60
4	NIKO	Standard Poodle	3	Female	21	60

Fig. 5. Information on the four dogs used in the evaluation experiment.

Fig. 6. The target individuals (four dogs) responding to an external stimulus (camera).

The evaluation method used in this experiment was different from that used in the previous research. In the prior study, we evaluated the success rate of waking of the communication equipment using the features of synthetic acceleration. Video camera recorded to evaluate the synthetic acceleration data and the habit behavior of a target dog when throwing a ball with it. In this study, in order to generate a more accurate evaluation of the time of the threatening behavior, we allowed each animal to continue to encounter other individuals for about 20 s from the start of the experiment, and evaluated the number of times the communication device was woken by each algorithm for one encounter.

4.2 Evaluation

The threatening behavior algorithm was evaluated with respect to the number of times the communication device was woken for $G' = 1.2, 0.8, 0.4$. We acquired synthetic acceleration data from the acceleration sensors attached to (1) KURT, (2) KARL and (3) JASMINE, but could not acquire data from (4) NIKO due to a terminal malfunction. We evaluated the experimental results based on the data from these three animals.

The experimental results presented in Fig. 7 show that number of activations in this proposed algorithm is higher for each threshold compared with the number of existing algorithms. The number of activations in the threatening behavior algorithm $G' = 0.4$ is approximately eleven-point-two-five times higher than in the prior algorithm, indicating that the maximum accuracy is high for all individuals.

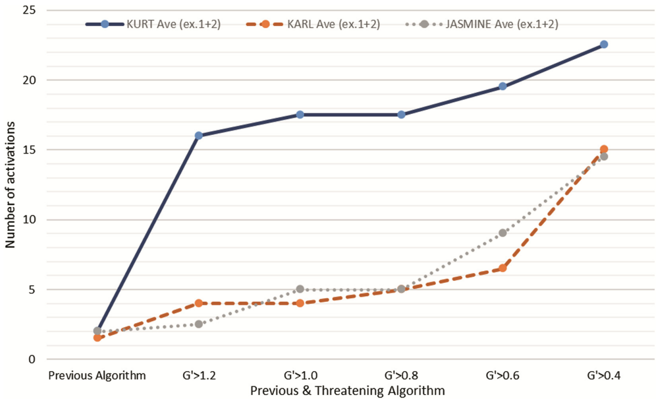

Fig. 7. Experimental results (number of activations vs. each algorithm).

It can therefore be said that threatening behavior when encountering other individuals can be detected more efficiently by our proposed method than by existing algorithms.

5 Discussion

5.1 Improvements to Data Communication Throughput

Using the proposed algorithm, which considerably improves the detection success rate for waking the communication device during threatening behavior, it is possible to consider incorporating the existing method of efficient data transfer into a wireless space. For example, since half-duplex communication and communication with a base station have basically a one-to-one correspondence in the radio space, the waiting time for the next communication is a factor that lowers throughput. IEEE 802.11n/ac implements a frame aggregation method called A-MPDU [9] to reduce waiting time as far as possible and to improve data transfer performance. In the present technology, headers such as carrier sense and acknowledgment (ACK) become unnecessary every communication, by connecting a large number of data transmissions from the base station, and receiving a large amount of data in one frame on the client side. Overhead is reduced for the whole data transfer, enabling more efficient data transfer by this method.

In prior research, for data transmission and reception between two individuals, bidirectional communication based on the order determination using preamble and ACK of data transmission/reception has been assumed; however, insufficient examination of improvements to data transfer throughput has been done. In this study, we narrowed the encounter pattern to include only threatening behavior, and optimized encounter detection, improving the detection rate more than tenfold. In addition, by shortening the stationary time in the algorithm to a tenth of that in the existing algorithm, the duration between the actual encounter and detection of the encounter by the algorithm has improved, extending the data transfer time, and an overall improvement in throughput can be obtained. In addition, throughput can be improved, for example by the use of a frame aggregation method that reduces the overhead due to the ACK, as mentioned above, ensuring stable end-to-end wireless communication and improving the detection rate.

5.2 Power Savings for Animal Wearable Interfaces

Improvements to the throughput of data transfer in inter-individual communication are important for environmental survey methods using wild animals in infrastructure-free environments; however, power savings are also important, and this is always a trade-off with data transfer. Animal wearable devices can only add 2–5% of the weight of the animal, and there are therefore severe restrictions on battery capacity. Since the system operation time depends on the battery life, improvements to battery performance and power savings are important in long-term monitoring over several years that takes spatial and time-series expansion into account. In this research, we focus on power saving, and show that it is possible to efficiently detect events such as encounters.

Beacon technology utilizing Bluetooth or BLE is not a realistic detection method for this system, due to its high power consumption. It is therefore important to improve the efficiency of data transfer while maintaining power savings by operating only the acceleration sensor, which has low power consumption, in order to improve the feasibility of this system. While the proposed method improves the encounter detection rate and improves the data transfer efficiency, power savings are also achieved by operating only the acceleration sensor.

6 Applications

A report published by the International Atomic Energy Agency regarding the Chernobyl nuclear disaster of 1986 [6] stated that it is academically and socially important to conduct ecological studies of the levels and effects of radiation exposure on wild animal populations. Here, long-term and wide-range monitoring is required to understand the effects of such a nuclear accident. For the more recent Fukushima nuclear disaster of 2011, we have little evidence regarding the direct effects of radioactivity on wildlife [7]. As reported in [7], Ishida has begun conducting regular ecological studies of wild animals in the northern Abukuma Mountains, near the site of the Fukushima Daiichi nuclear power plant; high levels of radiation have been detected in these mountains. Ishida aims to place automatic recording devices at over 500 locations and has already collected and analyzed the vocalizations of target wild animals.

When monitoring species in this way, counting the recorded calls of animals is often an effective method, since acoustic communication is used by many types of animals including mammals, birds, amphibians, fish and insects [2]. In addition to visual counts, this method is commonly used to investigate birds and amphibians [2]. An observer listens to calls and identifies species from the recorded data. However, this method has a disadvantage in that the result is affected by the lack of an information and electrical power supply infrastructure.

To address this limitation, wearable sensors can be used for wild animals (Fig. 2). To collect the data recorded by these wearable sensors, it is necessary to recapture the monitored subjects; thus, wearable sensors are limited to collecting data from the recaptured subjects' habitats. To solve the problems with existing systems, the proposed project will develop a system where wild animals are fitted with a wearable sensor, the spatial information in their territory is recorded via their individual actions, information obtained through group actions (with reduced power requirements) is shared, and this shared information is eventually uploaded to the Internet.

7 Conclusion

This paper proposes a method for communication equipment wake control for encounters through active behavior against external stimuli. Specifically, it involves three or more contacts between acceleration sensors attached to animals; each sensor is triggered to wake the communication device to transmit and receive data between the animals' devices when threatening behavior against an external stimulus is detected. In order to evaluate this algorithm, evaluation experiments were conducted using four standard poodles. In order to more accurately evaluate the time of the threatening behavior, we set conditions for continuing to encounter other individuals for about 20 s from the start of the experiment, and evaluated the number of times the communication device was woken by each algorithm in one encounter. With cooperation from veterinary researchers, we set up a condition where strangers passed immediately in front of the dogs' run, in order to generate the threatening behavior used to trigger waking of the communication equipment between two individuals.

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