Applicability of a Wireless Fidelity Positioning System to Tracking Free-range Domestic Fowl (*Gallus gallus domesticus*) and Helmeted Guineafowl (*Numida meleagris galeata*)

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Abstract. This paper reports the results of an experiment for testing the applicability of a Wireless Fidelity (WiFi) positioning system to tracking free-range chickens. In this system, the location of a chicken on a continuous plane (an experiment field) at any time was represented by a point (referred to as a *location point*) on a one-meter square grid lattice, and the trajectory of a chicken by the sequence of its location points. The system recorded the location point of a chicken at every second. The experiment used eight Domestic Fowl (*Gallus gallus domesticus*) and two Helmeted Guineafowl (*Numida meleagris galeata*), which were kept freely in a park (170 by 90 m), where their spatial behavior was observed for five days. The complete data were collected for three days. Because the observed location points contained random noise, they were treated as probabilistic variables. Data analysis showed that location accuracy was 2.6 m with a probability of 0.95. The living space of a chicken was represented by a two-dimensional probability density function of location points. The function was estimated by the kernel method with the bi-weight kernel function whose bandwidth was 2.6 m. The trajectory of a chicken was estimated by the moving average method. This experiment showed that the WiFi positioning system was practically applicable to tracking free-range chickens.

Key words: Free-range Domestic Fowl, Helmeted Guineafowl, Tracking, Wireless fidelity (WiFi) positioning system.

Introduction

One of the major tasks encountered in studying animal spatial behavior is to acquire the trajectory data of animals (Turchin 1998). To achieve this, two systems have been frequently employed in animal ecology: the global positioning system (GPS) (see, for

Received 21 March 2006.

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example, the conference proceedings, Tracking Animals with GPS 2001) and the telemetry system (e.g., Millspaugh & Marzluff 2001). Although both systems are useful in practice, they are not always effective under some conditions. At present, the lightest GPS receiver is around 65 g, which is, as shown by Ando and Ogasawara (1970), difficult to fix on an animal whose weight is less than 1 kg. GPS receivers are weak at tracking animals that move under trees, bushes, houses, etc. Because the telemetry system requires human manipulation, it is difficult to track many animals simultaneously over a long period (including night time). To find an alternative method that overcomes these shortcomings, an experiment was carried out, in which a Wireless Fidelity (WiFi) positioning system was applied to tracking a fairly large number of free-range chickens for several days, to test whether the system could give precise data of their trajectories.

Methods

To track free-range chickens, the WiFi positioning system, which was developed by AeroScout and distributed by NEC NetsSI in Japan, was employed. The system consists of six components: tags, location receivers, activators, Power over Ethernet (PoE) hubs, a WiFi access point and a management engine.

Tags are fixed on moving objects (e.g., chickens in this study; Fig. 1) and send signals of location data through radio waves. The weight of a tag is 35 g and its size is 62 mm × 40 mm × 17 mm.

The location receiver (Fig. 2) detects signals of location data in radio waves sent from tags and sends the detected signals to a management engine (to be described later). The receiver has an antenna, of which there are three types: nondirectional (Fig. 2a), 135-degree directional (which covers a fan-shaped area with a 135-degree angle; Fig. 2b) and 60-degree directional. The receiver may be fixed on a pole (Fig. 2a, where the height was 3 m) or on a fence (Fig. 2b).

The activator (included in the box of a location receiver) controls the power of the tag.

The PoE hub supplies the location receivers with electric power and gathers the

Fig. 1. A tag fixed on a chicken with natural tabular Teflon tapes.
signals of location data sent from the receivers.

The WiFi access point connects the PoE hubs and computer devices. The management engine is a software package that processes signals of location data sent via the WiFi access point and displays the locations of tags.

The major function of the WiFi positioning system is to capture the x–y coordinates of moving objects every second over a long period (e.g., a few months). Location accuracy of the data depends on the environment where the WiFi positioning system is installed and the number of receivers. The primary objective of this report was to examine this accuracy.

The experiment field was a park in Tokyo, whose area was about 170 m × 90 m enclosed by fences, walls and buildings (the bold lines in Figure 3). The region indicated by the vertical lines in Figure 3 was a sloping area covered with tall trees, and the difference in height was about 6 m. Visitors at this park during the experiment were very few.

The configuration of the devices mentioned above is illustrated in Figure 3. Twelve
location receivers with activators were placed at the (partly) filled circles, two PoE hubs at the white circles, one WiFi access point at the gray circle and one management engine at the hatched circle. Cables, indicated by the continuous hairlines in Figure 3, connected these devices (the WiFi access point and the management engine were connected by radio waves indicated by the broken line).

The subjects of this experiment were 10 chickens (Table 1): three White Leghorn cocks, two White Leghorn hens, one male Satsumadori (a Japanese native Domestic Fowl Gallus gallus domesticus), one female Satsumadori, one Hybrid hen and two male Helmeted Guineafowl. They were obtained from the Research Institute of Evolutionary Biology and kept in the henhouse indicated by the left rectangle in Figure 3 for two weeks before the experiment started. A tag was fixed on the back of the chickens with natural tabular Teflon tapes produced by Bally Ribbon Mills (Fig. 1). The total weight of the tag and tape was 40 g. Almost all chickens were soon accustomed to wearing the tags except for the male Satsumadori (5BEEAA), which disliked it for several hours. Note that three Helmeted Guineafowl did not wear tags (in total, five Helmeted Guineafowl were used for our experiment).

The experiment started on August 5, 2005 with letting the chickens out of the henhouse. The chickens were kept free with a small amount of mixed food until August 9 when the tags were taken off. The weight and weight gain during this period are shown in the fifth and sixth columns of Table 1, respectively. Complete data were acquired on August 6, 7 and 8. During the experiment period, the weather was fine. It was noticed from the WiFi positioning system and confirmed by dead bodies that one male Satsumadori (5BEEAA), one Hybrid hen (5BF25E) and one Helmeted Guineafowl (5BEEAB) were killed, probably by raccoon dogs or stray cats on the nights of August 6, 7 and 8, respectively.

Table 1. Chickens used for the experiment.

<table>
<thead>
<tr>
<th>Tag ID</th>
<th>Species</th>
<th>Varieties</th>
<th>Male/female</th>
<th>Weight (kg)</th>
<th>Weight gain (kg)</th>
<th>Place to obtain</th>
</tr>
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<tbody>
<tr>
<td>5BF25E</td>
<td>Gallus gallus domesticus</td>
<td>Hybrid</td>
<td>f</td>
<td>3.27</td>
<td>NA</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BEEAA</td>
<td>Gallus gallus domesticus</td>
<td>Satsumadori</td>
<td>m</td>
<td>2.65</td>
<td>NA</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BED51</td>
<td>Gallus gallus domesticus</td>
<td>Satsumadori</td>
<td>f</td>
<td>1.8</td>
<td>−0.2</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BF292</td>
<td>Gallus gallus domesticus</td>
<td>White Leghorn</td>
<td>m</td>
<td>1.52</td>
<td>0.1</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BEEA8</td>
<td>Gallus gallus domesticus</td>
<td>White Leghorn</td>
<td>m</td>
<td>1.8</td>
<td>0.06</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BF293</td>
<td>Gallus gallus domesticus</td>
<td>White Leghorn</td>
<td>m</td>
<td>1.37</td>
<td>0.14</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BEEA7</td>
<td>Gallus gallus domesticus</td>
<td>White Leghorn</td>
<td>f</td>
<td>1.78</td>
<td>0.1</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BF296</td>
<td>Gallus gallus domesticus</td>
<td>White Leghorn</td>
<td>f</td>
<td>1.17</td>
<td>0.13</td>
<td>RIEB</td>
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<tr>
<td>5BED57</td>
<td>Numida meleagris galeata</td>
<td>Helmeted Guineafowl</td>
<td>m</td>
<td>2.32</td>
<td>0.18</td>
<td>RIEB</td>
</tr>
<tr>
<td>5BEEAB</td>
<td>Numida meleagris galeata</td>
<td>Helmeted Guineafowl</td>
<td>m</td>
<td>2.22</td>
<td>NA</td>
<td>RIEB</td>
</tr>
</tbody>
</table>

NA: not available
RIEB: Research Institute of Evolutionary Biology
Results

The WiFi positioning system represents a point on a continuous plane by a point on a one meter square grid lattice (referred to as a 1 m-grid lattice). Consequently, a continuous trajectory of a chicken is represented by a sequence of discrete location points on the 1 m-grid lattice. The minimum discernible distance between two location points is 1 m.

The location data of killed chickens enabled us to examine the accuracy of the location data. Figure 4a shows the raw data of location points of a killed chicken (5BEEAA). Because the killed chicken stayed at a fixed point, the location points were supposed to remain at the same point. However, as is seen in Figure 4a, observed location points were scattered, indicating that the data contained random noise. To reduce random noise, extreme location points were discarded through a filter that reflected the fact that chickens could not run faster than 5 m/s. Figure 4b shows the location points obtained through this filter. The fixed point where the killed chicken lay was estimated by the average of the filtered location points. Given this average location point, the accuracy of the location points was measured in terms of the radius of the circle in which 95% of random location points were included (Fig. 4c). The radius was 2.6 m. This is one of the major results of this experiment, indicating that the true location is likely to exist within the 2.6 m circle centered at an observed location point with probability 0.95. This accuracy is more precise than a lightweight GPS whose accuracy is stated to be around 10 m.

Because of the above probabilistic nature, the living space of a chicken is represented by the probability density function of location points (the sequence of location points will be discussed later). One of the most commonly used methods for estimating this density function is the kernel method (Silverman 1986). This method was employed with the bi-weight kernel function, whose bandwidth was chosen as 2.6 m because of the above degree of accuracy.

First, the density functions of five White Leghorn chickens over three days were estimated. The observation of these functions indicated that the density function was almost the same with respect to the five individuals and with respect to each day. Figure 5 shows the density function of location points of a White Leghorn cock (5BF292) for three days (from 5 am to 6 pm). The gray area in Figure 5, which consists of 1 m × 1 m
cells, indicates that the cock visited that particular cell at least two times during the three days, and the contour lines represent the surface of the density function.

Second, the density functions of the male and female Satsumadori were estimated. Because the male Satsumadori (5BEEAA) was killed on the first day, only one density
function was obtained for the female *Satsumadori* (5BED51). Inspection of the density function for three days shows that it was almost the same for the three days. Figure 6 depicts the density function of location points over the three days.

Third, the density function of the Hybrid hen (5BF25E) was estimated. Because this hen was killed on the second day, the density function was obtained for only one day and is shown in Figure 7.

Last, the density function of Helmeted Guineafowl was estimated. Because one Helmeted Guineafowl (5BEEAB) was killed on the third day, its density function was obtained for two days and that of the other Helmeted Guineafowl (5BED57) for three days. The observation of the density functions (Fig. 8) indicates that the density functions of the two Helmeted Guineafowl were different on the first day. On the second day, however, as noted in Figure 9, their density functions became almost the same, which were very different from either of the distributions on the first day (compare Figs. 8 & 9). The density function of the surviving one (5BED57) was almost the same for the last two days.

Comparison between Figures 5–9 provided a few more findings. First, individual differences appeared between Guineafowl on the first day (Fig. 8), but the differences disappeared on the second day (Fig. 9). In the night of the first day, one male *Satsumadori* was killed between the two gray areas in the left panel of Figure 8 (see also

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Fig. 8. Contour lines of the density of location points of two Helmeted Guineafowl (5BED57 (right), 5BEEAB (left)) on the first day (from 5 am and 6 pm) (the gray area consisting of 1 m×1 m cells indicates that the males visited at least two times at that cell (1 m×1 m) on the first day).

Fig. 9. Contour lines of the density of location points of two Helmeted Guineafowl (5BED57 (right), 5BEEAB (left)) on the second day (from 5 am and 6 pm) (the gray area consisting of 1 m×1 m cells indicates that the males visited at least two times at that cell (1 m×1 m) on the second day).
The living spaces of the free-range Domestic Fowl and Helmeted Guineafowl differed among varieties and species (see Figs. 5–9). The living spaces of White Leghorn, Satsumadori and Guineafowl were almost exclusive on the first day. On the second and third days, the living spaces of the White Leghorn and Guineafowl overlapped slightly but were still quite exclusive (contour lines did not overlap). These findings indicate the existence of territories among these varieties and species. However, as is seen in Figures 6 and 7, the living spaces of Hybrid and Satsumadori overlapped.

The above findings were obtained from the aggregated data of location points without considering their sequence (i.e., a continuous trajectory). The next concern was whether or not the data of location points could be used for analyzing trajectories. One might think that a trajectory would be simply given by joining consecutive location points. This is true only when the location data did not contain random noise. As mentioned above, the data contained random noise, and so the line obtained from joining consecutive location points was a zigzag even after location data were filtered using the 5 m/s assumption (Fig. 10).

One of the most frequently used methods for estimating a trajectory from noisy location data is the moving average method. To be explicit, let $x_i$ be a location vector at time $i$ (seconds) of a chicken. The moving average method transforms a sequence (trajectory) $x_1, x_2, x_3, x_4, x_5, x_6, x_7, \cdots$ into a sequence of averages $(x_1 + \cdots + x_k)/k, (x_2 + \cdots + x_k)/k, \cdots$.


\[ \frac{x_1 + \cdots + x_k}{k}, \frac{x_2 + \cdots + x_{k+1}}{k}, \frac{x_3 + \cdots + x_{k+2}}{k}, \frac{x_4 + \cdots + x_{k+3}}{k}, \frac{x_5 + \cdots + x_{k+4}}{k}, \text{等} \]  

Figure 11 shows the trajectory of a White Leghorn cock (5BF292) from 6 am to 7 am estimated by the moving average method, where \( k = 17 \). When \( k = 17 \), the moving average location was always within the 2.6 m circle for a fixed location point.

The experiment reported in this paper showed that once the WiFi positioning system was installed, it automatically provided trajectory data, required less manpower than the telemetry system, could monitor 10 chickens at the same time, could track animals that moved under trees and bushes, and could track animals for several days.

**Acknowledgments**

We express our thanks to Dr. Kohoji Shiraishi of the Research Institute of Evolutionary Biology for providing the chickens and Guineafowl; to Mr. Kiyokawa Ozaki and Mr. Shigemoto Komeda of the Yamashina Institute for Ornithology for instructing us how to fix tags on chickens; and to Dr. Schu Kawashima of Tokyo University of Agriculture and Mr. Jun Yagi of Jun Royal Company for conducting the experiment.

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