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(Attached Form 6)

学位論文の要旨（論文の内容の要旨）
Summary of the Dissertation (Summary of Dissertation Contents)

論　文　題　目
Dissertation title
Agro-Environmental Study on Grazing System: Sensing Grazing Behavior and Spatial Modeling

広島大学大学院国際協力研究科
Graduate School for International Development and Cooperation, Hiroshima University
博士課程後期　開発科学専攻
Doctoral Program　Division of Development Science
学生番号　D133798
Student ID No.
氏　名　吉利　怜奈　㊞
Name　Seal

Spatio-temporal information on the grazing behavior of animals provides insights into pasture and animal conditions, allowing for improved pasture management and animal care. Various sensors and analytic tools have been developed to assist with the collection and analysis of data regarding the activities of animals at pasture. However, most of these devices cannot be used by farmers because they are only capable of taking measurements for a few days, due to their high energy consumption, or because they are expensive and require extensive experience to correctly attach them to animals. Moreover, the data obtained by such sensing devices are complex, and the grazing behaviors are strongly influenced by surrounding environments.

The objectives of this study were (1) to develop a simple tool for determining cattle grazing behavior in the pasture (chapters 2 and 3), and (2) to predict spatial distribution of cattle excrement, one of the main sources of greenhouse gas (GHG) emission from pasture, using Bayesian approach (chapters 4 and 5) and unmanned aerial vehicle (UAV) on-boarded camera images (chapter 6).

The global positioning system (GPS) data sometimes contains many missing values. In chapter 2, thus, the author tried to determine the minimum requirement of GPS recording rate (100% = 1,440 GPS points per day) that is sufficient to know the spatial distribution of livestock (especially, distance traveled). Using 1,000 simulations of random sampling method between 75 (1,080 GPS points per day) to 100% recording rate, daily distance (m) traveled by cow was calculated. The results indicated that there is no significant difference between 91−100% GPS recording rate on the distance (t-test, $p > 0.05$). The 1,459 days from five-year data set were greater than 91% of the GPS recording rate in one day and used for appropriate in determining the spatial distribution of cattle. The distance traveled tended to have similar trends that younger cows walked longer distance. During the daytime, the cows mostly stayed in the lower-altitude area of the paddock, while during the nighttime, the cows spent most of their time in the higher-altitude area of the paddock.

In chapter 3, the author evaluated the feasibility of an accelerometry-based activity monitor, the Kenz Lifecorder Ex (LCEX; Suzuken Co. Ltd., Nagoya, Japan), combined with a GPS, in order to differentiate between foraging and other activities of beef cows in a steeply sloping pasture. The grazing trial was conducted in a mixed sown pasture (0.85 ha) and four cows from the 20 cows were fitted LCEX-GPS collars in four days (June 14–18, 2010). During the period, three researchers recorded the animal activities (eating, resting and ruminating) and postures in every minute for 15 hours. Logistic regression (LR) and linear discriminant analysis (LDA) – two of the most widely used techniques for distinguishing animal activities based on sensing device information – were applied to the dataset (LCEX and observation data) to distinguish eating and other activities (resting, ruminating, etc.). The LDA results showed a higher correct discrimination percentage for all cows (90.6–94.6%) than that of the LR results (80.8–91.8%). Applying the LDA function over the whole period of LCEX data, the time spent eating averaged 443–475 min day^{-1} (30.7–33.0%). Combining with the GPS locations, the spatial distribution patterns of eating and other activities of cattle were compared between daytime and nighttime. During the daytime, the cows mostly grazed in the lower-altitude area of the sloped paddock, covering a wider area than that at nighttime. Meanwhile, at the nighttime, the cows spent most of their time in the higher-altitude area of the paddock, without eating activity. These results are in agreement with the results of chapter 2 and other previous researches.

In chapters 4 and 5, the spatial distribution of cattle dung was estimated based on Bayesian approach using generalized linear mixed models (GLMM) with an added intrinsic conditional autoregressive (CAR) term. The predicted herbage green biomass (GBM) with rising plate meter (RPM) and distance from a water trough (D_w), which can be controlled by farmers, were considered as predictors in the models. The field experiments was conducted in three mixed sown pastures (I and II, 1.02 ha; III, 0.85 ha) in Hokkaido, Japan. After a four-day grazing trial using 20 Japanese Black cows (*Bos taurus* L.), the paddocks were divided into 10 m × 10 m grid cells (I and II, 102 cells; III, 85 cells) and for each grid cell the number of dung deposits (N_d) was counted and the mean values of the GBM and D_w were computed using geographical information system (GIS). First, the spatial distribution of cattle dung was estimated using single paddock data (chapter 4). Then, the model was improved to be more general and used three paddocks data (chapter 5). The results of a Markov Chain Monte Carlo (MCMC) simulations indicated that a higher N_d tend to be associated with a higher GBM and locations closer to the water trough. The N_d showed spatial autocorrelation and it is likely that the grid cells that have large residual values could be affected by the difference between cattle activities in the daytime and nighttime. These results suggested that the spatial distribution of cow dung can be predicted from two controllable factors in short term grazing trials. Ideally, farmer use this knowledge to control the excrement position by managing grass condition and changing a water trough location.

In chapter 6, the author tried to detect the position of cattle dung in pasture using a very high resolution image acquired by a UAV on-boarded camera. In a grazed paddock (1.0 ha), two control plots A and B (20 m × 20 m, protected from cow by electronic fence) were installed, and UAV images were acquired on June 20, 2014. The spatial resolutions on ground level in plot A and B images were 1.4 cm (1891 × 1929 pixels) and 2.2 cm (1222 × 1228 pixels), respectively. After the UAV flight, the position of cattle dung were recorded using differential GPS (DGPS) and ground survey. Image processing was done using random forest regression (RFR) analysis to determine cattle dung from RGB image values. The results indicated that the fresh dung could be detected with high accuracy from the image using RGB values with their size and shape information. Meanwhile, old dried dung is difficult to distinguish from soil due to similarity of RGB values. The subject of a future study could be look for a characteristic wavelength to distinguish between old dung and soil. It is necessary to consider the short-wavelength (ultra violet) and near-infrared (NIR) not just the visible region (RGB colors) and investigate whether it is possible to distinguish how many days after excretion the fresh dung looks like old dung. The author also detect the dung position with other photographic images provided by the UAV at different altitudes and verified the size estimate precision.

Limitation of this study is that the actual amount of GHG emissions resulting from livestock excrement in the pasture were not quantified. Future study requires to examine the actual GHG emissions from a grazing pasture in order to establish precise GHG mitigation techniques. Nevertheless, the knowledge of livestock excrement position could be useful for farmers to minimize environmental pollution. The result of this thesis could contribute to do precision agriculture that can minimize environmental effects and enhance productivity.