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Human-Centered Design of Cattle Behavior Monitoring System for Grazing in Abandoned Farmland

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ABSTRACT

This research incorporated human-centered design into the development of a user interface (UI) that informs farmers of data on the behavior of grazing livestock. The designed UI generated communication among farm stakeholders and encouraged them to take action when the monitoring system detected unusual cattle behavior. It was confirmed that the process of human-centered design is effective in the livestock industry, which faces a serious labor shortage problem and can benefit from the further implementation of IT.

Keywords: Human-Centered design, Precision farming, Grazing, Cattle behavior, Disease, Communication, Prototype

INTRODUCTION

The livestock industry faces a severe shortage of workers due to population outflow from rural areas to urban areas and the aging of the population (Taylor et al., 2012). Scholars have thus made efforts to collect and analyze big data and its usage to simultaneously achieve precise livestock farming and labor cost reduction (Wark et al., 2007). In this context, the Food and Agriculture Organization of the United Nations (FAO) has stated that there is a need to promote research that addresses the needs and demands of the small to midsize and family farmers (FAO, 2014), in other words, human-centered design (HCD). However, compared to fields such as medical and care where HCD has been widely applied (Ohashi et al., 2021), there is very little research that has applied HCD in the livestock sector. The purpose of this study is to apply HCD to the development of the user interface (UI) of a cattle behavior monitoring system, "PETER," using edge AI and GPS, which enable the detection of the behavior (e.g., eating, ruminating, walking, resting) and locations of grazing cattle (Li et al., 2021a; Li et al., 2021b).

METHODOLOGY

In this study, we developed a UI for a behavior analysis device using a grazing pasture in Shimane Prefecture, Japan, as a field. In this pasture, two beef breeding cows (Japanese Black breed) graze on about 1 ha of abandoned land. The pasture is currently managed by a local farmer (hereinafter, the "farmer"), who used to graze the cattle, by outsourcing. The farmer visits the pasture every morning and evening for about an hour to feed the cattle and check their health. The person requesting the outsourcing of the work is an employee of the company that owns the pasture, who lives 700 kilometers away in Tokyo (hereinafter, the "owner"). As the owner is a licensed veterinarian, he is consulted remotely when any problems arise. Therefore, the target users of the HCD in this study were the farmer and the owner.

The R&D process was organized based on the HCD framework as defined in ISO 9241-210 (*ISO,* 2019). In HCD, the following four processes are supposed to be repeated until the product meets the user's needs: a) Understanding and specifying the context of use, b) Specifying the user requirements, c) Producing design solutions, and d) Evaluating the design. In this study, these processes were conducted for three rounds, as described in Table 1. In addition to the farmer and the owner, the developer of the behavior analysis device and a livestock expert were also interviewed to provide expertise.

The purpose of Round 1 was to organize the problem situation and confirm the ideas and concept. The observation items from the fieldwork and the data from the interviews with the farmer and the owner were open coded to organize the problem situation, and from there the issues considered high priority were extracted to define the requirements for the product (Burnard, 1991). They then listed the ideas, created a figure representing the concept (sketch), and showed it to the users to receive feedback on whether the requirements were on target and whether the ideas could meet the requirements (Szekely, 1995; Walker et al., 2002).

Next, in Round 2, we aimed to revise and improve the ideas. Based on the results of Round 1, we identified the problem, defined the requirements, and created a web app without actual functions, but which the participants could use as a mock-up. In addition, in testing notifications from the web app, we used the Wizard of Oz method by sending test notifications to the existing chat app instead of the mock-up to check the user's response (Dahlbäck et al., 1993). Here, we prepared multiple candidates for notifications, including graphs and phrases, and checked with the users to see which ones met their requirements.

Finally, in Round 3, we created a web app using actual livestock data (functional prototype) and had users use it for 30 days. At the middle and the end of the user test period, a five-point Likert scale questionnaire on whether each function was useful (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) and a semi-structured depth-interview were conducted to verify that each function met the respective requirements. In addition, based on the chat communication app records, we observed how communication was generated by the farmer and the owner during notifications.

Table 1. The R&D process organized based on HCD.

	HCD process	Activity	Data source	Time
Round 1	a	Fieldwork / Interview	farmer	3 Nov. 2020
		Interview	owner	3 Nov. 2020
	b	Defining requirements		Nov. 2020
	c	Expert interview / prototype	device developer	3 Nov. 2020
			livestock expert	17 Nov. 2020
	d	User test and interview	owner	11 Dec. 2020
			farmer	18 Dec. 2020
Round 2	a, b	Revision of problems / requirements		Dec. 2020
	c	Expert interview and prototype	device developer	21 Dec. 2020
			livestock expert	15 Jan. 2021
	d	User test / interview	owner	19 Jan. 2021
			the farmer	21 Jan. 2021
Round 3	c	Expert interview / prototype	device developer	Jan.–Apr. 2021
	d	User test / interview	owner	Jun. 2021
			farmer	Jun. 2021

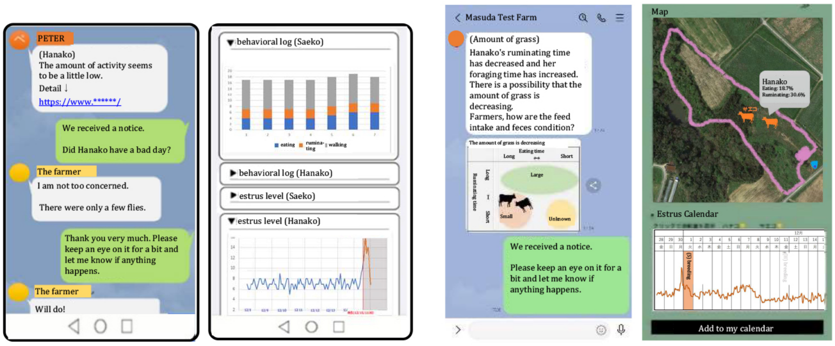
RESULT

Round 1: Organize the Problem and Confirm the Idea Concept

As a result of open coding of the observation items from the fieldwork and the speech data from the interviews with the farmer and the owner, 19 issues were found. Of these, we extracted and organized problems that were considered high priority and those that could be solved by PETER, and defined three requirements.

The first requirement was as follows: "Veterinarians and advisors in remote areas will be able to notice signs of estrus, disease, and nutritional abnormalities and consider how to deal with them, without waiting for consultation from managers in the field" (Requirement 1-1). The requirement is reflected the structural problems of this farm. That is, the farmer is in the position of receiving orders/instructions from the owner, and on the other hand, the owner has to notice and deal with the problems of estrus, disease, and nutritional management of cattle; however, they cannot drive to the site because they live in a remote area. Thus, conventionally, the only way for the owner to make decisions was to wait for the farmer's notification of the problem and consult with them.

The second requirement was as follows: "Veterinarians who do not normally see the cattle will be able to treat diseases without relying solely on the memory of the manager" (Requirement 1-2). This was set in the hope that the PETER information also would be useful to local veterinarians who would have the responsibility of dealing with the estrus, disease, and nutritional management problems noticed in Requirement 1-1.



(a) (b) (c) (d)

Figure 1: Prototypes. (a, b) Sketches in Round 1. (c, d) Mock-ups in Round 2.

The third requirement was as follows: "Veterinarians and advisors in remote areas will be able to design feeds with a clear rationale" (Requirement 1-3). This was determined based on the issue that regarding grazing on abandoned land where the amount of grass is not abundant, the missing nutrition is supplemented by roughage, but since it is not known how much grass the cattle are eating while grazing, it is not known how much roughage should be fed to them, which causes the cattle to be undernourished, resulting in reproductive problems.

We conceived the idea based on these requirements and created figures to represent the concept. Some of them are shown in Fig. 1. Figure 1(a) shows a function that notifies the communication tool (*LINE Corporation*, n.d.) that the farmer and owner have been using when it detects signs of estrus, disease, or nutritional abnormalities. This corresponds to Requirement 1-1. It is thought that it is possible to detect estrus based on the 21-day estrus cycle and changes in the activity of cows, and illness based on changes in activity time; regarding nutritional deficiency, while it is difficult to estimate the absolute amount of forage, it is possible to grasp signs of changes in the amount of grass based on the relationship between ruminating and eating time (Ertjmry, 2007). Although it is not clear that such information from these behavior analysis devices alone would be sufficient for the owner in a remote area to decide how to deal with the situation, we expected that this notification would encourage the farmer and the owner to become aware of the situation, and that the farmer would be able to give explanations supplementary to the notification so that the owner could give instructions on how to deal with the situation on the spot. Figure 1(b) is an app that allows users to refer to the condition of the pasture and past activity data, corresponding to Requirements 1-2 and 1-3.

Based on these figures, we obtained feedback from the farmer and owner on the requirements and the concept. The results were that Requirement 1-1 was acceptable, and both the farmer and the owner had high expectations for the notifications in the communication tool. In particular, they expected that the change in the amount of grass would be one of the factors involved in decision making, even if such information was not complete, because they had to deal with reproductive problems among cattle due to lack of nutrition in the past. On the other hand, they were not sure if they needed to see the past behavioral history. There were also requests for other functions, such as knowing the expected date of estrus and calving, knowing where the cows are when they do not come to the feeder, and knowing when they are stuck due to accidents.

Round 1 user testing showed that notifications to the communication tool and app for archiving are expected to be effective. However, whether these meet the requirements depends on the wording of the notification and how the data is presented. As some information on the problems and needs in the field was updated, it was decided to revisit the problem from the problem organization and requirements definition in Round 2.

Round 2: Brushing up on Ideas

We redefined the requirements in the following three categories, incorporating the issues identified in Round 1: "Veterinarians and advisors should be able to recognize the possibility of poor health, nutritional deficiencies, and accidents even from remote locations without waiting for consultation from managers in the field, and gather the information necessary to make decisions" (Requirement 2-1); "The timing of events related to estrus and childbirth can be scheduled in advance, and the timing at which treatment is needed will not be missed" (Requirement 2-2); "Locate cows when they do not show up following calls for them from the on-site manager" (Requirement 2-3). Based on these requirements, we created a web app without real data, and for the notification function, we confirmed the response of the farmer and the owner through test notifications sent by the author. We prepared several candidates for the display method of each function and the wording of the notifications, and asked the users which among them satisfied the requirements better. Figure 1 (c) and (d) are the excerpts.

In terms of notifications, we incorporated feedback such as the link to the app is not being referenced when sent, so it would be better to post the diagram as is, and the earmark number is better than the name for identifying cows. Regarding the app, we adopted a graph that shows the amount of activity per day, a diagram that estimates the amount of grass based on the relationship between ruminating time and foraging time, a map that shows the location of the cows as well as their own location and the range of the pasture, and an estrus and calving calendar that overlays changes in the amount of activity of the cows. However, since we needed to experiment with actual data to see if these requirements were actually met, we decided to create a functional prototype in Round 3.

Round 3: User Testing with an App Using Actual Livestock Data

Based on what was discussed in Round 2, we created a web app as a functional prototype that incorporates actual cow behavior data and has a notification function for the chat app (Fig. 2), and had the farmer and the owner use it for 30 days to verify whether or not Requirements 2-1 and 2-3 were met. Requirement 2-2 could not be verified because there were no

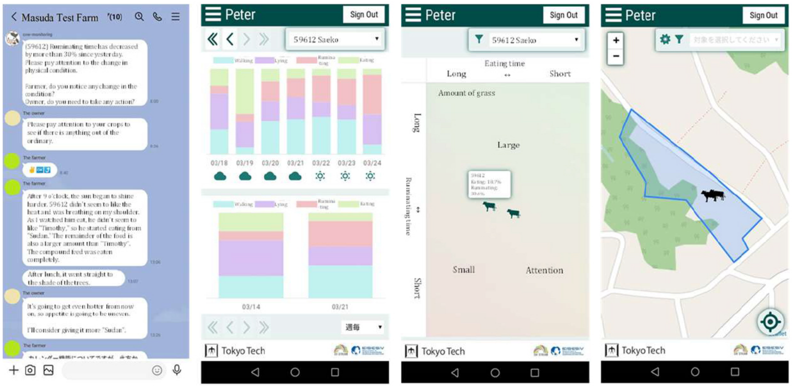


Figure 2: Screenshot of functional prototype in Round 3.

estrus or birth events during the user test period. Also, accident notification in Requirement 2-1 could not be verified because no accident occurred.

First, the notification was set to arrive before the farmer's morning work when the activity time of each cattle in the past 24 hours changed more than a certain percentage compared with the preceding 24 hours. The thresholds were adjusted accordingly by the authors so that each of the following types of notification could be tried within the user test period: decrease in rumination, decrease in foraging, decrease in walking, and increase in resting. The app was made available to use for free, with graphs showing daily and weekly changes in the amount of each activity, a diagram showing the amount of grass, and the pasture map. After the user testing, the farmer and the owner answered a five-point Likert scale questionnaire on whether the information was useful or not. A semi-structured depth-interview was also conducted regarding usage and potential improvements.

During the month of user testing, there were 10 notifications in total, 8 of which resulted in the farmer providing supplemental information, 6 of which resulted in owner responding, and 1 of which resulted in a response to call a local veterinarian. The day the local veterinarian was called, a cow had diarrhea. That morning, there was a notification of a change in the amount of ruminating, and when the farmer looked at the cattle, the cow did not look well, so the farmer consulted the owner and the veterinarian was called. According to the questionnaires after the user test, the owner could not say whether the notification itself was useful or not, but the owner thought that the supplementary information was strongly useful. In the interview, the owner said, "The role of PETER is as a trigger, a lubricant to facilitate communication," and "It may be a trigger for me to take action. However, when it comes to deciding what to do, I rely on the supplementary information provided by the farmer." On the other hand, the farmer responded that they thought the notice itself was useful, saying, "When I receive the notification, I look at the cows and check if there are any abnormalities, as PETER indicated." These results did not differ according to the type of notification. Therefore, rather than the specific content of the notifications, it is thought that the notifications themselves, which indicate that something is unusual, were valuable. These prompted the farmer to direct attention and provide sensory support, and for the owner in remote areas to help him make decisions at an early stage.

Regarding the app, the farmer rarely looked at the weekly activity graph, but did look at the daily activity graph almost every day. Regarding the grass amount graph, the farmer said, "I can't say what percentage is too much or too little," and in the questionnaire on whether the function was useful, they answered "neither agree nor disagree." Regarding the map, the farmer answered "disagree" in the questionnaire on whether the function was useful. This was because the GPS was not accurate in mountainous areas, and the location of the cattle was often shown to be far from the farm. Based on these results, we considered that requirement 2-1 was partly achieved by the notifications and the daily activity graph. Decision making regarding poor health among cattle was achieved, but that regarding nutritional deficiencies was not. The reason for this is that the ruminating and eating times of the cows varied greatly (Kilgour, 2012), and it was not possible to determine one cow's ideal nutritional management at that time. It will be required to analyze not only individual cows but also a herd and to track the changes over time to get data of the grass amount. Requirements 2-3 were also not achieved due to the GPS accuracy problem. It will be necessary to devise a way to accurately acquire location information in mountainous areas.

CONCLUSION

As a result of adapting HCD to the field of pasture-based livestock farming, it became clear that problems faced by such farmers can be identified and that a UI that can be incorporated into their daily work can be designed. The actual UI is such that when the cattle behavior analysis device detects unusual behavior, it notifies the communication tools of the stakeholders, which attracts their attention, generates communication between them, and as a result, leads to early action. If this product is realized, even if on-site farm managers do not have sufficient skills or time to observe the cattle, breeding management of grazing cattle may become possible with the support of knowledgeable people in the surrounding area. In future research, we aim to resolve the technical problems of how to represent the grass data and the accuracy of GPS, and to test the product with multiple farmers.

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