Designing a Livestock Monitoring System and Evaluating the Performance of LoRa for a Farm

— Reforming agriculture by information and communications technology in Society 5.0 —

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***Abstract*—In this paper, we present an outline of our livestock monitoring system using long range (LoRa) in a low-power wide-area network and evaluate the performance of our LoRa device for use as a livestock monitoring system. We herein present the purpose of the project, an evaluation of LoRa transmission distance on a farm, and the application of our results. On the basis of our evaluation of LoRa, we confirm that it is a feasible technology for monitoring the behavior of livestock, particularly cows, on large farms.**

Keywords- grazing; high quality milk; behaviour tracking; ph of stomac; LoRa; AI.

I. Introduction

Several changes recently occurred in the methods of farm management in Japan. Farm size has become more extensive and efficient, promoting the American large-scale herd-management method. As a result, Japanese-style breeding management, which is based on a relationship of trust with livestock, has been lost. Breeding selection has dramatically improved the lactation ability of cows, but it led to a decline in body condition and weakening of reproductive behavior, primarily because of the lack of energy. Accordingly, artificial insemination at the correct time presents difficulties; it was reported in U.S. that the rate of successful pregnancies of cattle has been reduced to roughly 30% in the late 1990s (which was previously 60% in the late 1970s) [1], and in Japan to roughly 46% in 2009 (which was previously 60% in 1989) [2]. As a result, the number of cows and the production of raw milk have decreased.

Fine-grained, low-stress feeding management can reduce morbidity, increase reproductive efficiency, and improve the quality of raw milk. Breeding management that involves taking care of each animal and maximizing its individuality and ability can lead to the production of high-value-added milk. In this context, grazing is currently attracting attention

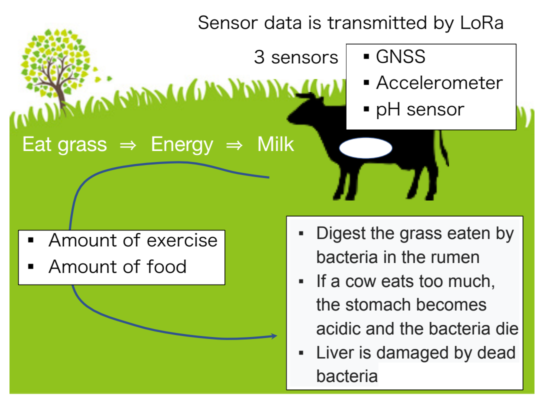

Figure 1. Cow's health condition

for its ability to manage cows in a less stressful and more natural environment. The relationship between the production of high-value-added milk through pasturing and observing the feeding behavior of cows while grazing and the overall health status is not entirely clear.

The aim of this paper is to clarify the relationship between grazing and the quality of raw milk and to subsequently develop a milk-quality-estimating system using sensors, information and communications technology, and Artificial Intelligence (AI).

This paper is organized as follows. In Section II, we explain the design of our proposed system. Section III introduces related research. In Section IV, we discuss the long-range (LoRa) [3] technology (included in ARIB STD-T108 in Japan [4]). In Section V, we explain an experiment for measuring the communication distance of LoRa in a different environment in detail. Finally, Section VI presents our research results and Section VII concludes the paper.

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II. SYSTEM DESIGN

Generally, cow health must be maintained to ensure the production of high-quality raw milk. Fig. 1 shows the relationship between a cow's health and its behavior. An outline of this study is presented in Fig. 2.

To measure the effect of grazing, we set three technical targets as follows:

- Target 1: Real-time tracking of cow-feeding behavior
- Target 2: Real-time measurement of cow rumen pH levels
- Target 3: Application of a machine-learning model to estimate the quality of raw milk

The outline of each target is explained in the following subsections.

A. *Real-Time Tracking of Cow-Feeding Behavior*

Purpose: To understand the behavior of cows while grazing and investigate the relationship between this behavior and milk quality.

Tasks:

Develop a sensor box that can detect location (Global Navigation Satellite System, GNSS) and accelerometer data. Send the data to a server via LoRa.

- The number of steps and the number of chewing cycles are estimated from accelerometer data.
- Activity is estimated from the walking distance calculated using location data.

B. *Real-Time Measurement of Cow Rumen pH Levels*

Purpose: To understand the health situation of cows and clarify the relationship between the pH level and the quality of raw milk.

Tasks:

- Develop a pH sensor that can be used on rumen and that can send data external to the cow's body.
- Develop a communication system to send a pH sensor outside the rumen.

C. *Machine-Learning Model for Estimating the Quality of Raw Milk*

Purpose: To estimate the quality of raw milk from the behavior and pH level of cow rumen.

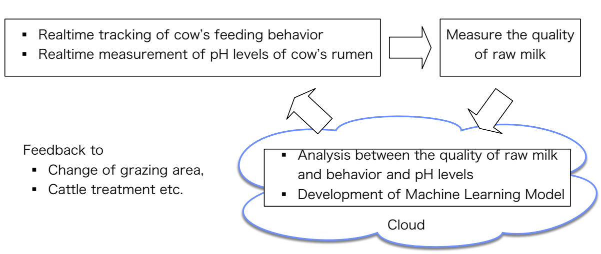

Figure 2. The outline of this study.

Task:

- Develop a machine-learning model to estimate the quality of raw milk from the behavior and pH level of cow rumen.

In the following two sections, related work and a technical outline of LoRa will be described.

III. RELATED WORK

Many studies have measured the behavior of livestock. In [5], a method was introduced to track the movement of cows using a black-and-white pattern of the surface of a cow house. In [6], a location-detection technique in a cow house using ultrawideband and tags was presented. In [7], a technique for observing the cow-feeding behavior using an accelerometer in a cow house was addressed. All of these technologies focus on the use of a cow house.

In [8], a technique for monitoring locomotion and posture activity was presented, but no function for transmitting data to the server in real time was provided. The work in [9] explains system aspects such as nodes, gateways, and servers and is based on a LoRa wide-area network (LoRaWAN). However, in that study, no real field tests were conducted. In [10], the performance of LoRa and custom protocols for monitoring livestock was discussed; however, hypothetical situations are always slightly different from the conditions on a real farm.

IV. LORA

Low-Power Wide rea (LPWA) [11] is a type of network that is becoming popular for LoRa license-free wireless communication technologies. This type of network can provide news services for long-distance communication (from several hundreds of meters up to several kilometers) in rural areas. Additionally, LPWA operates at the subgigahertz (sub-GHz) band, which has excellent penetration. It is expected that LPWA will be able to provide several useful features for Internet of Things (IoT) applications, such as low cost, low-power consumption, long-distance communication, connection of a significant number of IoT devices, and small-scale data transmission (ranging from 100 bps to 1 Mbps).

It is highly expected that LPWA will be used for communication technologies in IoT systems. This technology has the following features:

- Low cost
- Low-power consumption, except for Bluetooth Low Energy and ordinary near-field communication technologies, which require a generous power supply
- Long-distance coverage (from several hundreds of meters up to several kilometers)
- Connectivity to multiple devices
- Transfer of small amounts of data at speeds ranging from 100 bps to 1 Mbps

The most popular LPWA standard is LoRa [3]. The LoRa Alliance particularly defines LoRaWAN [12]. LoRa defines the modulation technology of the physical layer of a chip, and LoRaWAN also includes a media access control layer. Furthermore, LoRaWAN specifies the interoperability of

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TABLE I. EFFECT OF SF AND BW ON TIME-ON-AIR (MS) (FROM THE ES920LR DATA SHEET IN [11])

(A) PAYLOAD IS 10 BYTES

Combination of BW x SF good for the long range communication (62.5KHz, SF=12)

		Spreading Factor (SF)					
		7	8	9	10	11	12
Band Width (BW) (KHz)	62.5	144	247	453	823	1483	2966
	125	72	123	226	412	741	1483
	250	36	62	113	206	371	741
	500	18	31	57	103	185	371

(ms)

Combination of BW x SF good to send large data (500KHz, SF=7)

(B) PAYLOAD IS 50 BYTES

		Spreading Factor (SF)					
		7	8	9	10	11	12
Band Width (BW) (KHz)	62.5	308	534	903	1642	2957	5587
	125	154	267	452	821	1479	2793
	250	77	133	226	411	739	1397
	500	38	67	113	205	370	698

(ms)

TABLE II. TEST PATTERNS.

	Category	*Features*	*Location*
Case 1	Forest	Trees and mountain	Oku-Nikko
Case 2	Farm for livestock (flat area)	Covered by grass	Utsunomiya Univ. farm
Case 3	Farm for livestock (mountain area)	Covered by grass	Ozasa Farm in Nikko
Case 4	City	Buildings	Eng. Department of Utsunomiya Univ.

LoRa devices. LoRa employs chirp spectrum spread, thereby allowing long-distance communication.

When using LoRa, two parameters must be included: bandwidth (BW) and spreading factor (SF). A smaller BW allows for communication across a longer distance, whereas a larger SF allows for communication over a longer distance. However, if we wish to achieve communication over even longer distances, we need to select appropriate parameters. The relationship between the BW and the SF of the ES920LR LoRa chip that we used in 2019 is described in Table I.

V. EXPERIMENT

We performed several trials to check the communication distance of LoRa.

A. Locations

In order to check the communication distance, we used four locations as follows:

(1) Oku-Nikko: flat, wide forest and marsh in the Nikko National Park (400 ha, roughly 4 × 4 km).
(2) Utsunomiya University Farm: flat farmland with some trees (50 ha, roughly 1 × 0.5 km).
(3) Near the Engineering Department: city area with buildings and factories surrounding the campus area.
(4) Ozasa Farm: one of the largest livestock farms in Japan (362 ha, roughly 4 × 4 km).

B. Devices and GNSS Data

We developed a LoRa device using the following parameters.

(Oku-Nikko)	(Farms and Utsunomiya Univ.)
– BW: 125KHz	– BW: 62.5KHz
– SF: 10	– SF: 12
– Tx power: 13dbm	– Tx power: 13dbm
– LoRa chip: RAK811	– LoRa chip: ES920LR
– Antenna gain: 0dbi	– Antenna gain: 0dbi

In these experiments, the transmitted data, including the GNSS location data, were 35 bytes. According to Table I, we estimated that one data could be transmitted within 5 s. Fig. 3 shows the receiver and transmitter that we used in the experiment conducted at Ozasa Farm, both of which used the same LoRa chip (ES920LR [13]). The transmitter had a GNSS receiver and sent location data to the receiver.

Receiver Transmitter

Figure 3. Receiver and Transmitter

C. Okumura-Hata Model

The Okumura–Hata model [14][15] is an approximate curve used for estimating the radio-wave propagation characteristics of wireless devices at the development stage of mobile communication systems in different environments in open areas; suburbs; and small, medium, and large cities. The equations shown in Fig. 4 were used for loss calculation. In the experiment, we measured not only the communication distance but also the fitting of the Okumura–Hata model. If

$$Loss(dB) = A + B\log(d) - \alpha + C$$

where

$A = 69.55 + 26.16\log[f(MHz)] - 13.82\log[h_b(m)]$

$B = 44.9 - 6.55\log[h_b(m)]$

f(MHz): frequency

d(km): distance

h_b(m): base station height

α and C depend on the location

For example, if the location is an open space, α and C are defined as follows:

$\alpha = \{1.1\log[f(MHz)] - 0.7\}hm(m) - \{1.56\log[f(MHz)] - 0.8\}$

$C = -4.78\{\log[f(MHz)]\}2 + 18.33\log[f(MHz)] - 40.94$

h_m(m): mobile station height

Figure 4. The Okumura–Hata model.

the results showed a good fit with the Okumura–Hata model, we would be able to use that model to estimate the reach of LoRa.

D. Experiments

We started performing LoRa tests in 2018 (see [16][17]) under different situations (e.g., in city, forest, and farm areas), as described in Table II. In [16][17], we reported the LoRa test results for three different cases (Cases 1, 2, and 4 in Table II) and confirmed that the communication distance closely fit the Okumura–Hata model.

We herein explain a recent experiment (December 3, 2019) conducted on a farmland in a mountainous area (Case 3 in Table II).

As previously noted, Ozasa Farm is one of the largest livestock farms in Japan (362 ha). Fig. 5 shows a panoramic view of the farm. We set a LoRa receiver at the center of the farm on a tripod (at a height of roughly 2 m) and then traversed the farm on foot holding two LoRa transmitters. As noted in Section 5-B, data including the GNSS location were transmitted every 5 s. We used a BW of 62 and an SF of 12 to achieve the highest possible sensitivity. Fig. 6(a) shows the trace of the transmitted location, and Fig. 6(b) shows the trace of the received data with location. The log shows that LoRa was able to cover almost all areas. Table III shows the message-receiving rate, which was on average greater than 80%. We believe that this result indicates that LoRa is a feasible measure for monitoring livestock. Fig. 7 shows fitting

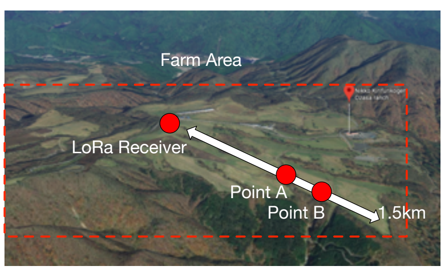

Figure 5. Panoramic view of the farm


(a) Transmitter trace

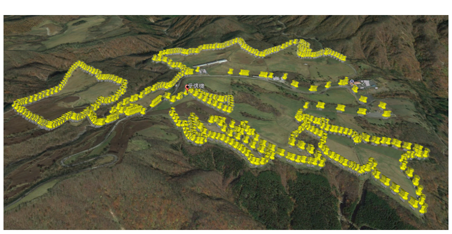
(a) Received data
Figure 6. Results of the LoRa test.

TABLE III. MESSAGE-RECEIVING RATE.

	Device 1	*Device 2*	*Total*
Number of transmitted messages	2,884	2,507	5,391
Number of received messages	2,272	2,113	4,385
Message receiving rate	78.78%	84.28%	81.34%

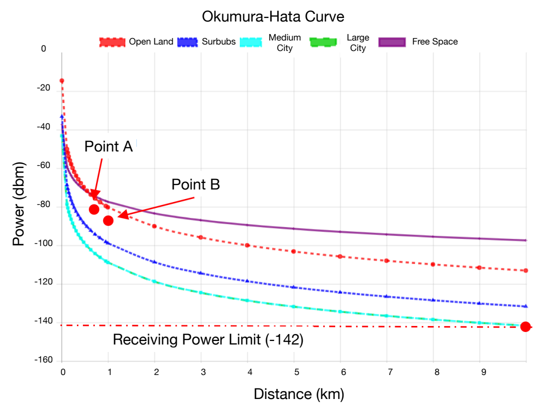

Figure 7. Fitting of the Okumura–Hata model.

of the Okumura–Hata model with these results. The results show that a loss occurred between open land and suburbs but that the results nonetheless met the requirements for Ozasa Farm. The Okumura–Hata model can, therefore, be used to estimate the potential of LoRa in a farm environment.

In the next step of our research, we will design sensor devices and a matching receiver for cows. If the transmitter sends data every 5 min and each data transmission requires 5 s, we will be able to obtain data from 60 cows using the same band. Each transmitter will have a GNSS device, allowing the scheduling of the transmission time for each cow without congestion. The LoRa device [13] will have 37 channels if the BW is narrower than 125 kHz; this will enable us to monitor 2,220 cows at the same time. Ozasa Farm generally supports 1,500 cows grazing on its pasture. As such, our system will be able to monitor them all.

VI. APPLICATION OF THE RESEARCH RESULTS

The Japanese Government is currently promoting the notion of *Society 5.0* [18], an idea that was proposed at the 5th Science and Technology Basic Plan (2016–2020) for conducting a future Japanese society. The aim of Society 5.0 is to achieve a high degree of convergence between cyberspace (virtual space) and physical (real) space. In Society 5.0, a significant amount of information from sensors in physical space is accumulated in cyberspace. In cyberspace, this big data is analyzed by AI, and the analyzed results are fed back to physical space in various forms to support society, business, and economics.

An outline of Society 5.0 for agriculture is described in Fig. 8. In order to solve problems related to agriculture and food,

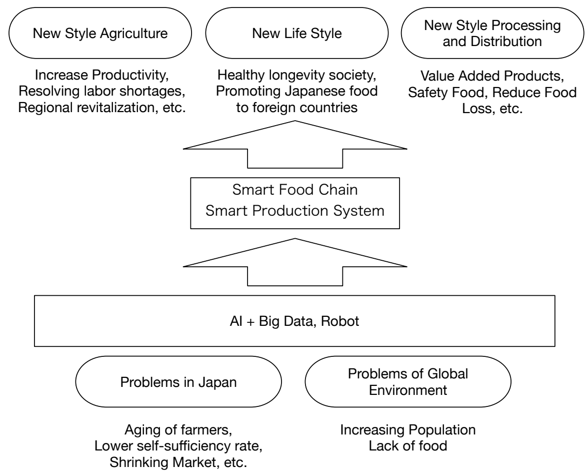

Figure 8. Agriculture in a Society 5.0 context.

Figure 9. Food-chain business model.

AI and big-data analysis technology are used to produce higher-quality primary products, such as milk, meat, and rice. Then, these high-quality products allow smart food chain and smart production systems to produce high-quality secondary and tertiary products. In addition, robots support the primary agricultural industry to solve problems such as aging among farmers. After realizing a new style of agriculture, we expect developing a new business model as illustrated in Fig. 9. Once we can produce high-quality raw milk, we will be able to produce high-quality butter and cheese and, subsequently, flavorsome sweets and dishes. The effect of such products and services is expected to promote gastronomy and health tourism.

The results of this research provide a potential platform for gathering real-time data from livestock within a wide area using LPWAs such as LoRa. Developing such a platform to gather data from sensors by LPWAs will serve as an important basis for reforming agriculture in a Society 5.0 context.

VII. CONCLUSION AND FUTURE WORK

In this paper, we introduced our research results for developing a monitoring system that can track the behavior of cows and pH levels for grazing and an AI model to estimate the quality of raw milk. With this research ongoing, we were able to explain in detail the performance of LoRa in a real situation. Accordingly, LoRa was able to cover the entire area of farmland evaluated. Furthermore, we also briefly addressed the broader scope of a new food chain business model based on the Society 5.0 context.

We hereby plan to develop a system based on the results of this research in the second quarter of 2020 and to evaluate said system by the end of 2020.

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