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Electrocardiogram Measurement and Emotion Estimation of Working Dogs

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Abstract— **Physiological measurements of dogs' emotional states during human-animal interactions are essential for understanding the underlying biological relationship. Heart rate measured by electrocardiogram (ECG) is an essential clue for the physiological measurement of emotional state. The activity of the autonomic nervous system caused by changes in the emotional state affects the heart rate variation. The heart rate variability can estimate human and dog emotional states. Soft disposable electrodes, which can be purchased commercially and reduce the risk of an injury on hitting hard objects, are used to measure the heart rate during working dogs' exercise. However, the heart rate measurements using soft disposable electrodes in M-X lead layout are unstable due to the detachment of electrodes during intensive movement. In addition, the collection of accurately labeled ECG data, which reflects the emotion of the working dog during exercise, is a key issue to conduct reliable estimation and visualization of the working dog's emotional states. In this paper, we propose an innerwear that fixes soft disposable electrodes in M-X lead layout on a dog's body for measuring the heart rates of exercising dogs, even during intense movement. We experimentally tested the proposed method using seven dogs. Our proposed system reduced the time required to attach soft disposable electrodes by more than two-thirds and enabled the measurement of >97% of the heartbeats in exercising dogs. We also proposed a method for collecting ECG data with reliable positive/negative emotional labels of search and rescue (SAR) dogs. A combination of the collected data with the emotion estimation algorithm proposed in previous studies estimated SAR dogs' positive/negative emotions at 97.9% accuracy. The transition of the two SAR dogs' emotions during drills was visualized using the collected data. This system can be used to measure the physiological and psychological state of exercising mammals in experimental studies and enhance the effectiveness of working dogs.**

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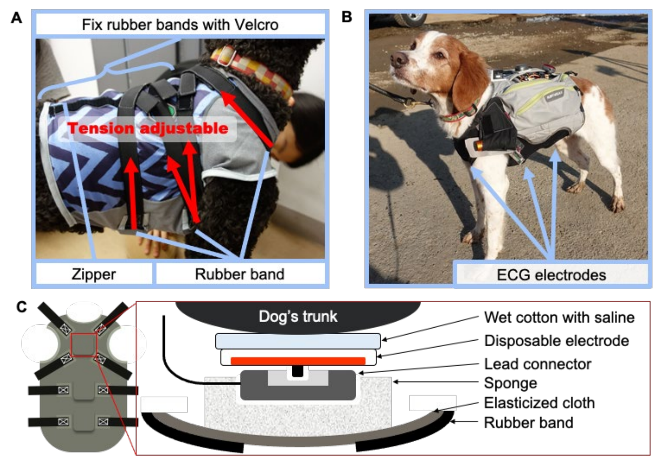

Fig.1. Electrocardiogram (ECG) measurement using innerwear and outerwear for dogs: (A) The proposed innerwear for an ECG measurement. (B) The proposed ECG telemetry suit fitted on a search-and recue dog. (C) A cross-sectional illustration of the proposed innerwear.

I. Introduction

Human-animal interactions are the subject of an interesting and relatively new scientific research field. Currently, dogs (Canis familiaris) are the best model animals for such studies. These animals have coexisted with humans for more than 30,000 years and are included as partners in human societies. During the domestication process, dogs have acquired human-like communication skills and can form emotional bonds with humans. The emotional connections between humans and dogs are strong, unique among mammals, and are thought to enhance human-dog co-habituation. Accordingly, dogs have acquired a unique niche in modern society. Some dogs even exhibit superior abilities to interact with humans, such as guide dogs for humans with disabilities and search and rescue (SAR) dogs.

In order to study human-animal interactions, it is necessary to measure bio-signal that indicates the emotional state of an animal. Heart rate is an important bio-signal that indicates the emotional state. This parameter is used to evaluate the state of the automatic nervous system in humans [1] and other mammals, such as rodents [2] and dogs [3]. Heart rate variability (HRV) is used to evaluate the states of the sympathetic and parasympathetic nervous systems, which are associated with emotion [4, 5]. Many studies have focused on the relationship between a dog's HRV and emotional responses such as empathy [6], anxiety [7], aggressiveness [8], and positive/negative emotions [9].

Electrocardiogram (ECG), a non-invasive method involving electrodes attaching to the skin, is frequently used to measure heart rate and HRV. Several electrodes are brought into close contact with the skin, and the ECG is measured from the potential difference between the electrodes. The electrodes must be stable and in close contact with the skin.

Wearable electrocardiography has been proposed for ECG measurement of active dogs [10,11,12,13]. In these studies, soft and hard disposable electrodes were brought into close contact with the body of pets and working dogs by using a jacket, a harness, and a strap. ECG data were measured during exercise and were used to monitor dogs' health and analyze the performance of working dogs. Several wearable devices provided wireless ECG measurement and visualization functions for online monitoring. These online functions will accelerate behavior monitoring and capacity expansion of working dogs.

Soft disposable electrodes, which can be purchased commercially, are well used for ECG measurements of working dogs because they can keep contact with the skin and can reduce the risk of injury on hitting hard objects during intensive exercise. There are three types of leads (M-X lead, L-R lead, A-B lead) for animals' ECG measurements. Previous research reported that ECG data by M-X lead is smaller fluctuation than A-B lead [11]. M-X lead is less susceptible to respiratory effects than L-R lead due to the electrode placement. Therefore, M-X lead was used to estimate emotions from heart rate variability [9,10]. Therefore, we selected M-X lead layout to measure ECG data for working dogs' emotion estimation.

However, it is difficult to conduct stable ECG measurements during exercise by attaching soft disposable electrodes to the M-X lead layout. The front chest and abdomen skins move significantly depending on the movement and posture of the dogs (walking, running, sitting, lying down). It causes the electrodes to shift or peel off [10]. Conventionally, the elasticized and self-fused bandages are used to wrap and stabilize ECG electrodes to the dog's abdomen; the dog must remain still while electrodes are attached to the body [9]. It is not easy to attach electrodes to the bodies of active dogs. Therefore, an affixing method of soft disposable electrodes for stable ECG measurements in exercising dogs is needed.

In addition, the collection of ECG data, which reflects the positive/negative emotion of the working dog during exercise, is a key issue to conduct reliable estimation and visualization of the working dog's emotional states. Machine learning is used for the estimation and these algorithms require training data with reliable labels.

Herein, we describe an easily wearable telemetry system to measure ECG signals and to estimate emotional state in exercising dogs (Fig. 1). We proposed an innerwear that affixes soft disposable electrodes at M-X lead layout on a dog's body using rubber bands and sponges. As the electrode devices are assembled in the innerwear, the heart rate can be measured during exercise while reducing the time needed to attach the electrodes. We tested the ECG measurement performance of our proposed system via experiments using five pet dogs and two SAR dogs. We also propose a method for collecting ECG data with reliable SAR dogs' positive/negative emotion labels. Accurate emotional estimation can be achieved by combining the ECG data with the emotion estimation algorithm proposed in previous studies. ECG data of two SAR dogs were collected and used to build an estimation model of emotional state. In addition, we visualized the change in the SAR dogs' emotional state during exercise. This new approach may reveal the biological mechanisms underlying human-dog co-habituation.

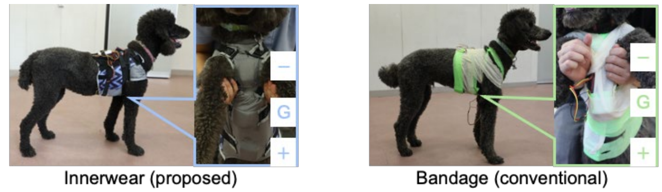

Fig.2. Fixed position of the ECG electrodes: (D) Our proposed innerwear, (E) Vetrap bandaging tape

The main contributions of this paper are as follows:

- Development of innerwear to affix soft disposable electrodes on dogs' body in M-X lead layout for heart rate measurements during exercises: Soft disposable electrodes can be stably attached to the dog's body in two-thirds of the conventional time. The heart rate variation in exercising dogs can be measured stably (online: 70.9%, offline: 97.7%). The R waves of SAR dogs can be detected at over 97% during training.
- Method for collecting SAR dogs' ECG data with reliable positive/negative emotional labels: We propose an efficient ECG data collection method for SAR dogs' positive/negative emotional states. Positive/negative emotional states are estimated using the previously proposed estimation algorithm and the collected ECG data. The estimation accuracy using the random forests algorithm was 97.9%.
- Visualization of the positive/negative emotional state of SAR dogs: The transition of SAR dogs' emotional state during the drill was visualized using the positive/negative emotion estimation method. We also visualized the positive/negative emotional states in a SAR dog, which is not included in the training data of the emotion estimation model on trial.

II. Innerwear and Outerwear for Dog's ECG Measurement

A. *Innerwear for stable electrode attachment*

We developed an innerwear to attach the ECG electrodes to the dog's body (Fig. 1 A and Fig. 1 B). Both soft disposable electrodes (Vitrode M; Nihon Kohden, Shinjuku, Tokyo, Japan) and pinch connectors were covered with sponges to enable close attachment to the trunk (Fig. 1 C). Saline-moistened cotton and a small amount of ECG gel were placed

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on the disposable electrode's contact surfaces and the dog's trunk to reduce impedance.

In the M-X lead, electrodes were positioned on the manubrium sterni (negative electrode), xiphoid process (positive electrode), and the midpoint between these points (ground) (Fig. 2). Subsequently, rubber bands were crossed, fastened to the negative electrode, and fixed on the dog's back using Velcro. The ground and positive electrodes were similarly stabilized to the dog's back using pairs of rubber bands and Velcro. Rubber bands were used so that the tension could be adjusted according to the size and shape of the animal. The sponges and rubber bands pushed ECG electrodes against the dog's abdomen to maintain stable attachment during intensive movement.

The proposed innerwear was developed based on a stretchable dog T-shirt (Dog Guard, ALPHAICON, Sapporo, Hokkaido, Japan). Specifically, the back of the T-shirt was cut, and a zipper was sewn in to facilitate placement while holding the garment and electrodes on the body. This innerwear simplified the electrode attachment procedure in three steps: placing the forelegs of the dogs through the sleeves, closing the zipper, and fastening the rubber bands (Please see the video material).

B. Outerwear for ECG measurement and telemetry

We also developed outerwear to record the ECG signals of dogs. ECG signal data were stored locally in this outerwear and were transmitted to cloud servers via a mobile phone network. It enabled the real-time monitoring of the heart rates of active dogs.

The details of the dog suit (outerwear + innerwear), recording devices, and transmission are as follows. A Singletrak Pack (Ruffwear Inc., Bend, Oregon, U.S.) was used as the dog suit for our measurement devices. An M-X lead was selected for ECG measurements because of its ability to remain stable during movement [11]. An R-R intervals (RRI) telemeter [14] capable of measuring an ECG signal and detecting R waves using automatic gain control and thresholding was selected as the ECG measurement device. The lead cables of the RRI telemeter were connected to disposable electrodes (Vitrode M) via pinch connectors.

The sensors were connected to a Raspberry Pi 2 model B single-board computer (Raspberry Pi Foundation, Cambridge, U.K), and the measured data were stored locally. Power was supplied to the devices using two LF1100–6.6V batteries (Tamiya Inc., Shizuoka, Shizuoka, Japan) with a charge capacity of 2 h. The measured RRI data were transmitted to a DynamoDB cloud NoSQL database (Amazon Web Services, Inc., Seattle, Washington, USA) via a mobile phone network and an Aterm MR04LN mobile WiFi router (NEC Corp., Minato, Tokyo, Japan).

C. R-R interval detection from ECG signal

Each dog's R waves were detected online and offline from an ECG signal measured at a sampling rate of 1000 Hz. The RRI is the time intervals between pairs of successive R waves in an ECG signal. The RRI telemeter in the ECG suit detected the R waves online based on the adaptive gain control and thresholding. It transmitted the timings of the detected waves

Experimental field for SAR dog(Dog ID:6)

Experimental field for SAR dog(Dog ID:7)

Fig.3. Experimental field setup to measure ECG data of positive/negative emotions

to the Raspberry Pi, which calculated and stored the RRI values. The ECG signal was also stored in the memory.

For offline detection, we detected R waves from the measured ECG signal using the findpeaks function of the MATLAB Signal Processing Toolbox (MathWorks Inc., Natick, MA, USA) after detrending. This function is based on thresholding and online detection of the RRI. The R waves were detected offline, and the results of detection and corresponding ECG signals were visually inspected by human annotators and corrected to yield the ground truth. Finally, the accuracy of the R waves detected online and offline was evaluated. The detection accuracy was calculated as the ratio of the number of correctly detected online or offline R waves to the number of R waves in the ground truth.

III. Emotion Estimation Method and Training Data

A. Emotion estimation using the random forests

Random forests algorithm and RRI time-domain indices were used to estimate the positive/negative emotions. The emotion estimation method was proposed in previous studies [9, 10].

The emotion estimation uses RRI time-domain indices : mean RRI (mean value of RRI), SDNN (Standard Deviation of NN intervals), RMSSD (Root Mean Square of Successive Differences), and pNN50 (NN50 (the number of pairs of adjacent RRI differing by more than 50ms) count divided by the total number of all RRI)). The time-domain indices can realize short time interval analysis [15]. ECG data are preprocessed by a bandpass filter that cuts 0-24 Hz for noise reduction. 15 s RRI data were used to calculate these indicators every second. The time of 15s was decided based on [9, 10] that introduces the estimation algorithm of positive/negative emotional states.

The random forests algorithm [16], one of the ensemble learning algorithms, was used to estimate the positive/negative emotions. It uses multiple weak classifiers and enables accurate identification based on data. The decision tree is used for the weak classifier. The input feature

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is $v = \{x_1, x_2, \cdots x_d\} \in R^d$, and the output is class c. $p(c|v)$ is calculated by the sum of the multiple weak classifiers' outputs. Here, v is the RRI time-domain indices and $d = 5$, and c is positive and negative labels (Posi=1 or Nega=0). In the training phase, c and v are used for making multiple decision trees. In the prediction phase, $p(c|v)$ is estimated from the output of the multiple decision trees for the input v.

The RandomForestClassifier of sklearn.ensemble Python API was used for the implementation. At training, the input data were the time-domain indices v with a label c every second. According to the previous studies, the number of decision three and the initial seed value were set to 100 and 0, respectively [10].

B. Training data collection of positive/negative emotions

We proposed a method for collecting ECG data with accurate SAR dogs' positive/negative emotional labels. SAR dogs were rewarded when they found a person via smell; however, they were not rewarded when they could not find a person. Positive/negative emotions are directly related to the finding/not finding of the victim during the SAR dog drill. The proposed data collection method can be used for the working dogs that use the sense of smell, but it cannot be used for general dogs that actively use visual information rather than odor.

Figure 3 shows the experimental setup for the ECG measurement of positive/negative emotions. We prepared five tents that people could hide inside. During positive data collection, two people hid inside the two tents separately. A SAR dog searched tents 1 to 5 in order via smell and barked to determine the location when they found the participants. The positive label was attached when the SAR dog found the victims.

During negative data collection, there were no people inside the tents. A SAR dog searched tents 1 to 5 in order via smell. Negative emotions gradually became stronger as the exploration continued. Therefore, the negative label was attached when the SAR dog searched the last two tents.

The intervals between these experiments were set to several minutes with air replacement to eliminate the residual scent.

IV. Evaluation of R Waves Measurement and Emotion Estimation

A. Evaluation of R waves measurement

1. Time required to attach electrodes to active pet dogs

We compared the time required to attach electrodes using our innerwear with that required for bandages (i.e., the conventional method). We measured the time taken to attach electrodes using five active pet dogs (Dog ID: 1,2,3,4, and 5). In the conventional method, we fixed the ECG electrodes to the dog's body surface by conventionally wrapping the positioned electrodes using a Vetrap bandaging tape (3M Co., Two Harbors, MN, USA).

2. ECG measurements of active pet dogs in an indoor experiment

Fig.4. Experimental field of SAR dogs' drill: One person is hidden inside the building. SAR dogs search for a person from the entrance of the building.

Table 1. Elapsed time to attach ECG electrodes to a dog

Dog ID	Bandage (s)	Innerwear (proposed) (s)
1	412.3	116.6
2	460.2	133.7
3	422.0	160.2
4	432.5	115.6
5	351.0	145.0
Ave.	415.6	134.2

We tested our proposed system using five active pet dogs (Dog ID: 1,2,3,4, and 5) indoor. The ECG signals of each dog were measured using two methods of electrode fixation: bandages (conventional method) and our newly developed innerwear. We evaluated the accuracies of the R waves detected online and offline from ECG signals comprising P, Q, R, S, and T waves. Accurate R-wave detection is essential for heart rate and HRV measurements.

An indoor experimental field was designed as a straight corridor with a width and length of 2.2 and 20 m, respectively. On one side of the corridor, a handler commanded the dog to lie down on the floor for the first 15 s and sit for the following 15 s. Then, the handler and dog trotted to the other side of the corridor and then returned to the starting position. Finally, the handler commanded the dog to sit and lie down for 15 s, respectively. This trial was repeated three times at approximately 1-minute intervals, and the handler fed each dog during the trials. All experimental procedures were approved by the Ethics Committee of Azabu University.

The accuracy of R wave detection from the ECG signals was calculated under two attachment conditions and was calculated and compared using the Wilcoxon rank-sum test [17] and Cohen's d values [18].

Table 2. Online/offline detection accuracy of R waves

Online detection accuracy of R waves.

Dog ID	Breed	Sex	Bandage (%)	Innerwear (proposed) (%)
1	Whippet	F	83.4	87.4
2	Standard Poodle	F	29.9	91.6
3	Saluki	F	92.8	45.1
4	Standard Poodle	M	28.7	69.6
5	Standard Poodle	F	35.7	60.8
Ave. (S.D.)			54.1 (28.3)	70.9 (18.3)

Offline detection accuracy of R waves.

Dog ID	Breed	Sex	Bandage (%)	Innerwear (proposed) (%)
1	Whippet	F	99.5	100
2	Standard Poodle	F	99.1	100
3	Saluki	F	100	94.8
4	Standard Poodle	M	90.4	93.6
5	Standard Poodle	F	97.6	100
Ave. (S.D.)			97.3 (5.1)	97.7 (3.6)

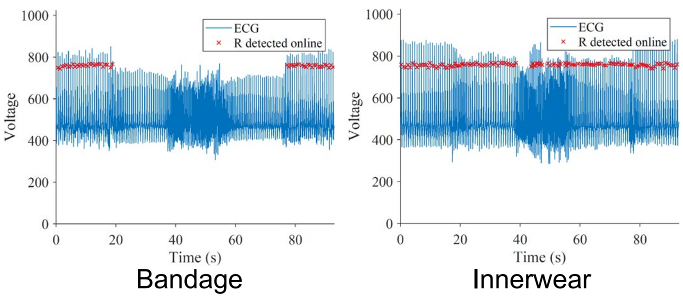

Fig.5. ECG measurement and R waves detection results

3. ECG measurements in SAR dogs' outdoor experiment

We tested our proposed system in an outdoor experiment using two SAR dogs certified by the Japan Rescue Dog Association (JRDA) (Dog ID: 6 and 7). The ECG electrodes were attached using only our proposed system, without shaving the dogs' body hair. We measured the ECG signals during simulated outdoor searches conducted during drills of JRDA, which is an incorporated nonprofit organization. During these drills, a handler commanded a SAR dog to locate people hidden somewhere at the search site. Detailed descriptions of these drills are presented in Fig. 4. All the experimental procedures were approved by the Ethics Committee of Tohoku University. The accuracy of the R waves detected online and offline was evaluated using the same tests described for the indoor experiment.

B. *Evaluation of positive/ negative emotion estimation of SAR dogs*

Two SAR dogs certified by the JRDA (Dog ID: 6 and 7) were used to collect positive/negative emotions. After measuring the positive data three times, negative data were measured once for each SAR dog. Data collection was conducted twice for each SAR dog. One negative data collection failed because one of the SAR dogs (Dog ID:6) found the remaining scent and barked. These data were removed to create the negative labeled data of the SAR dog (DOG ID:6).

In total, 24 positive and 6 negative data were prepared as time series data for emotion estimation. The total input data of the random forests was 531 RRI indices data with labels (469 positive and 62 negative data).

A cross-validation technique was used to evaluate the accuracy. For the cross-validation, the data were divided into five groups. The accuracy was evaluated using the following indices: accuracy, precision, recall, and F-measure [19].

Table 3. Online/offline detection accuracy of R waves for SAR dogs

Dog ID	Breed	Sex	Online (%)	Offline (%)	Description of task
6	Labrador Retriever	F	59.9	99.8	The canine was commanded to search for a simulated victim hidden in a closed school and the outdoor surroundings.
7	Brittany	M	69.1	97.9	The canine was commanded to search for simulated victims hidden in two of five small tents placed in an outdoor field.
Ave.			64.5	98.8	

C. *Visualization of emotional state transitions of SAR dogs*

We visualized two SAR dogs' emotional state transitions during the training drill. Two Labrador Retrievers (Dog ID: 6 and 8) were used for visualization. One was a SAR dog (Dog ID: 6) included in the training data for emotion estimation. For the visualization, we prepared ECG data that were not included in the training data of the emotion estimation. The other was a SAR dog (Dog ID: 8) not included in the training data.

SAR dogs' activities related to the found victim were manually labeled (searching, confirming floating odor, finding victim, and barking). SAR dogs check the floating odor to find a hidden person. They continuously bark when they find a hidden person. Therefore, we selected the labels mentioned above to analyze the transition of the emotional states. Humans watched the movies (Handycam and dog's suit camera) and attached these labels to the positive/negative emotions estimation results. All experimental procedures were approved by the Ethics Committees of Tohoku University.

V. Results of R Waves Measurement and Emotion Estimation

A. *Results of R waves measurement*

1. Time required to attach electrodes to active pet dogs

Our proposed system drastically reduced the time required for electrode attachment by approximately two-thirds compared to the time required by bandages (Table 1). This reduction can reduce the stress for both the researchers and dogs before the experiment.

2. ECG measurements of active pet dogs in an indoor experiment

In the online trials, the accuracy of R-wave detection was 70.9% with our proposed system and higher than with the use of bandages for electrode attachments (Table 2). There was a significant difference (p=0.0407 with one-sided Wilcoxon rank-sum test, Cohen's d=0.648) in online. Under the condition of bandage-only attachment, a height reduction in R waves led to a failure of signal detection when the dog changed its posture from sitting to lying down (Fig. 5, left). The height reduction was the reason for the difference accuracy.

On the other hand, in Saluki, the detection was 45.1%. This value was exceptionally lower than the

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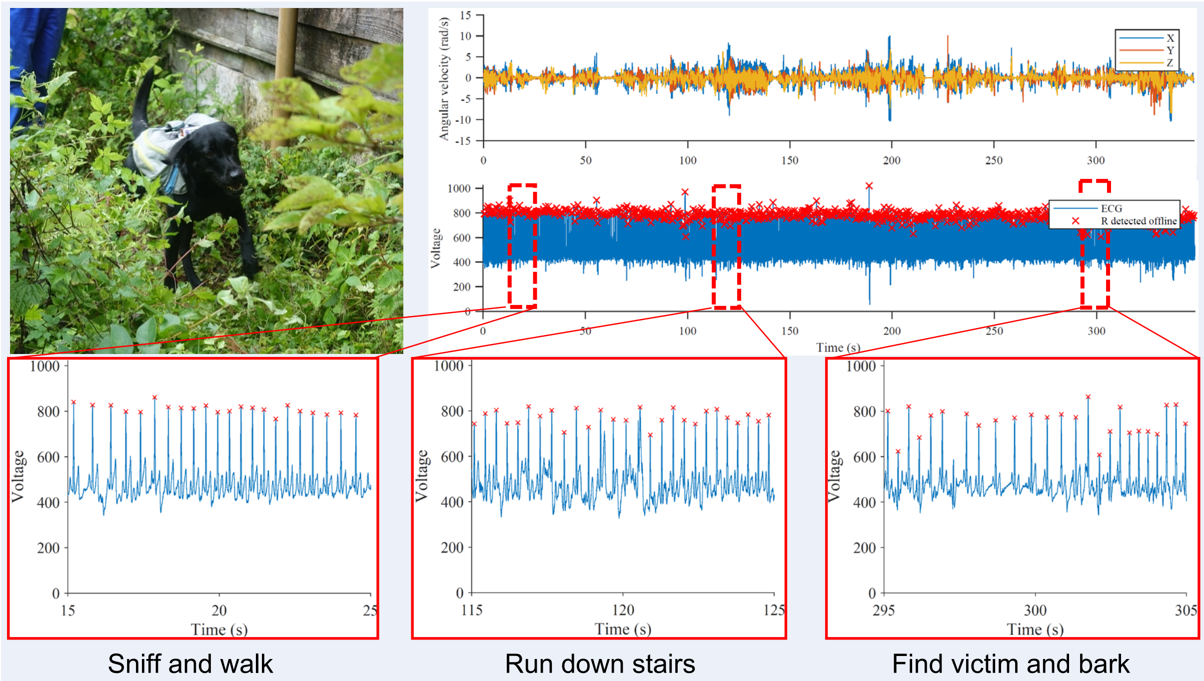

Fig.6. Outdoor electrocardiogram (ECG) measurement in a SAR dog (Dog ID:6) during a search

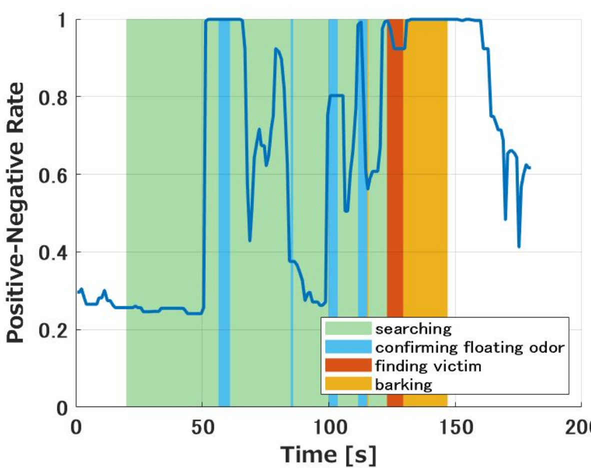

Fig.7. Emotion estimation of a dog (Dog ID:6) using offline RRI data: 0.0 is negative and 1.0 is positive.

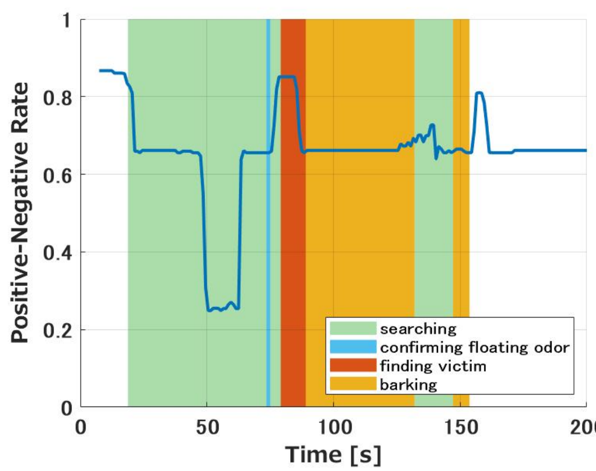

Fig.8. Emotion estimation of other JRDA certified SAR dog (Dog ID:8) using offline RRI data: 0.0 is negative and 1.0 is positive.

bandages and indicated that the online algorithm failed to detect the 55% R wave. The online algorithm caused it because the R waves were recorded correctly.

In offline trials, the accuracy of R-wave detection was more than 97% with our proposed system (Table 2). This accuracy was slightly higher than that of the conventional method, although it was not significant (vs. bandages, p=0.206 with one-sided Wilcoxon rank-sum test and Cohen's d=0.0756).

Some misdetections were observed owing to a reduction in the R wave height and increase in the P or T wave height. These misdetections can be reduced by a combination of thresholding and a differentiation-based detection algorithm, such as the Pan-Tompkins [20], wavelet-based [21], or filter bank-based algorithms [22].

3. ECG measurements in SAR dogs' outdoor experiment

In the outdoor experiment involving SAR dogs, R wave detection accuracy online and offline was 64.5% and 98.8%, respectively (Table 3). The use of innerwear enabled us to measure ECG data of SAR dogs during outdoor exercise. In addition, the ECG signals of both SAR dogs could be measured during outdoor exercise and when the body hair around the electrodes had not been shaved. It is an advantage of our proposed innerwear, which uses electrodes with moistened cotton.

Figure 6 shows the SAR dog (Dog ID: 6) ECG signal measured by the proposed suit (innerwear + outerwear). Although the SAR dog walked around the terrain like grass, abandoned houses, and stairs, the ECG data were measured using the suit. R waves were detected correctly in the offline processing.

B. Evaluation of positive/negative emotion estimation of SAR dogs

The cross-validation results are as follows. The accuracy, precision, recall, and F-measure were 0.9792, 0.9347, 0.8871, and 0.9080, respectively. These results suggest that the proposed data collection method can be used for gathering ECG data of SAR dogs' positive/negative emotions, and the accuracy of positive/negative emotion estimation is over 97%.

C. Visualization of emotional state transitions of SAR Dogs

Figures 7 and 8 show the graph of the SAR dog's (Dog ID: 6 and Dog ID: 8) emotional states. Positive/negative emotions were estimated from the RRI data during the drill. The estimation graph overlapped on the labels.

A strong positive emotion (close to 1.0) was observed where humans attached the labels of "the confirming floating odor", "finding victim", and "barking" in Fig. 7. In particular, when the SAR dog detected smell first and confirmed the hidden person using the smell and visual clue, the strongest positive emotions (close to 1.0) were estimated in Fig. 7. Positive emotions were mainly near the labels of "confirm floating odor" and "Find victim" and were estimated in a few seconds before and after the labels, as shown in Fig. 7. The wide existence of the positive estimation was related to the fact that the 15s RRI data was used calculate the RRI indices.

Figure 8 shows that the strong positive emotion was estimated near the labels "confirm floating odor" and "Finding victim" in the SAR dog (Dog ID: 8), which was not used for training the random forests. Although the tendency of the entire graph is different from Fig. 7, the strong positive emotion was observed when the SAR dog found the hidden person.

VI. DISCUSSION

The use of innerwear enabled us to affix the electrodes on dog skin quickly and to measure R-wave of dogs in exercise. Our proposed system reduced the time required to attach electrodes by more than two-thirds. It is important for reducing the stress of both humans and dogs. The proposed system enabled the measurement of >97% of the heartbeats in exercising dogs. The accuracy of online R-wave detection was drastically improved, and the accuracy of offline R-wave was slightly improved. Even a slight accuracy improvement is important for emotion estimation because 15 s R waves are used to calculate the RRI indices. If R-wave is lost, the emotion estimation cannot predict the correct emotion for 15s.

Our proposed ECG data collection method enabled us to estimate positive/negative emotions of SAR dogs with high accuracy of 97.9%. SAR dogs are rewarded for finding victims by smell during training. The finding a person is closely related to the positive emotion and vice versa. Therefore, SAR dogs' positive/negative data was collected through the simple task of finding and not finding a person.

Visualization of emotional changes during exploration gave essential results. When the SAR dogs found the smell of a person, positive emotions repeatedly appeared in Figs. 7 and 8. The results show that the positive emotion estimation might be used to judge SAR dogs' person-found actions. So far, the person who knows the dogs well has made a subjective judgment from the behaviors of SAR dogs. Instead of the person, AI might judge such important action. These are tentative results by using two SAR dogs. We will continually check these results as future works.

Research to enhance the capabilities of working dogs using robot and AI technology will become increasingly important in the future. Several studies suggested such bright futures of working dogs [23,24,25,26,27]. Understanding working dogs' emotions is an important key issue to help mutual understanding between humans and working dogs. Several studies have evaluated heart rate and HRV in working dogs [10,11,12,13,23]. The proposed method provided easy and reliable ECG measurement and emotion estimation of working dogs. These results will be possible to support other studies [23,24,25,26,27]. In addition, these results will lead to the development of new adaptation destinations for the robot and AI technology.

VII. CONCLUSION

We described an easily wearable telemetry system to measure ECG signals and estimate the emotional state in exercising dogs. We developed an innerwear to measure heart rate variation in exercising dogs. It was attached to dogs two-thirds of the conventional time, and the heart rate variation in exercising dogs was measured stably (online: 70.9% and offline: 97.7%). The R waves of SAR dogs were detected at over 90% during the training. We proposed an efficient data collection method for working dogs' positive/negative emotional states. The estimation accuracy using the random forests algorithm was 97.9%. The transition of SAR dogs' emotional state during the drill was visualized using the emotional state estimation method.

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