Stress Monitoring System Based On Heart Rate Variability Of Dog

Jeonghee Chi, Chaeeun Lee, Huiwon Yang, Moonsun Shin

Abstract: Recently according to the number of a pet owner is increased, many IoT services which could track the behavior or location of dogs are appearing. However, these systems focus only on the physical activities of dogs, and there is no service for recognizing positive or negative emotions of dogs. In this paper, we have developed the Bowow system that identifies the emotions base on Heart Rate Variability (HRV) of a dog. We have designed and built a wearable device that can be easily worn by dogs using a dog leash, and have enabled to users could observe in a real-time emotional state of a dog through a smartphone app. We experimented with several situations that people often tell or do to dogs in their daily lives. We have shown that the Bowow system could help communication between dogs and people.

Index Terms: Bowwow, Stress monitoring system, IoT, Heart Rate Variability, HRV, Stress of Dog, Emotion of Dog,

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1 INTRODUCTION

Recently, due to various social factors such as the increase of single-person households, aging, and low birthrate, the number of people who are raising companion animals is increasing. Many studies related to dogs among companion animals show that raising dogs has a positive effect on the health of adults and children [1-3]. The perception of dogs is changing beyond just animals to the notion of family, and dog owners are not only interested in the physical health of a dog, but also about in their mental health-related is increasing. Recently, many wearable devices such as TAGG, FitBark, and Whistle are emerging to manage the location and activity of dogs through the Internet of Things (IoT) [4]. Most of these devices are designed to check the activity or not, or location of dogs in real-time by installing an accelerator, GPS, motion detection sensor, or temperature sensor. These are performing functions to help maintain the proper body temperature of dogs measuring ambient temperature through temperature sensors or manage obesity by analyzing the activity amount of dogs. However, these devices focus on the physical health of dogs, and services to analyze the stress of dogs are not provided. To measure the stress of dogs, the blood tests should be taken at a specialized veterinary hospital. Recent studies have been conducted to measure the stress of dogs, but only a form that evaluates the level of stress through the expert's observation is performing [5].]. Recently, a study has been conducted that can measure the stress of dogs in the same way that people measure stress using Heart Rate Variability (HRV) [6]. Katayama et al. showed that HRV is useful for estimating the emotional state in dogs through 33 healthy house dogs.

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Although Katayama et al. showed that HRV is a useful indicator for evaluating dog stress, it is not enough to be service that checks and analyzes dog HRV in real-time. Therefore, it is necessary to develop a service that can improve communication between dogs and people by checking and analyzing the HRV of a dog in real-time. Hence, this paper aims to develop a service that can confirm the stress by measure the dog's HRV in real-time. Particularly seeks to develop a service that can help to understand the emotional state of dogs through experiments that test how words or actions that people do to dogs affect the emotional state of dogs and how much stress they feel when they are alone. The Bowow system proposed in this paper is composed to provide a service that allows the owner of the companion dog to easily grasp the condition of the dog by analyzing the data by smartphone device that received data of measuring the body temperature and heart rate of the dog by the wearable device attached to the temperature sensor and heart rate sensor in Arduino. This paper is composed as follows. In chapter 2, related works are described, and in chapter 3, Bowwow System Architecture is described. In chapter 4, implemented experimental results are described, and in chapter 5, conclusion and future research are described.

2 RELATED WORKS

The study that dogs are companion animals that have a useful effect on human health has long been conducted. About 30 years ago, J. K. Vormbrock et al. reported that human-dog interactions that talking to and petting a dog have affected lowering blood pressure [1]. In the current research, S. Uccheddu et al. showed that reading to a dog can have positive effects on motivation and attitude toward the reading of a child with Autism Spectrum Disorders(ASD)[2], and C. Wijker et al. showed that animal-assisted therapy with dogs could assist in reducing perceived stress and symptoms of agoraphobia in adults with an autism spectrum disorder[3]. Recently, various studies related to various IoT services to check dog health have been conducted. First, as a study to classify the dog's activities, G. M. Weiss et al. proposed a service called WagTag, they performed a study using the tri-axial accelerator to classify dog's activities as the minimal activity, walking activity, or running activity [7]. Also, J. M. Yashari et al. conducted a study to evaluate the function of a new motion-sensing devices-equipped Whistle that can be used to evaluate the physical activity of dogs as regards the performance of sensors in IoT devices [8]. Regarding services using smartphones, J. Alcaidinho et al conducted a study that providing dog data using smartphone applications could better understand the needs of dogs' activities and strengthen the bond between one's self and the adopted dog [9, 10]. In relation to the effect of tracking and monitoring dog activities, H. Väätä et al. showed that the use of a dog activity tracker has the potential to improve relationships with dogs, as the owners spend more time with their dogs and can better observe their own actions [11]. As a result of these studies, dozens of dog activity trackers and monitoring devices are currently being sold. However, their studies can only analyze data on a dog's physical activities, such as tracking its location or activity but are not being provided services for dog stress. In order to measure the dog's stress is through the experts to observe their behavior or measured them through blood tests at a specialized veterinary clinic. In a recent study, A. C. Stellato et al. also, through the experts to observed and evaluated the situational video recordings to be evaluated the stress index of dogs due to noise [5]. However, these methods have a problem that it is difficult to determine the degree of dog stress in real-time. Recently, studies have been performed that HRV is the major indicator of dog stress measurement [6], but it is not providing real-time stress services yet.

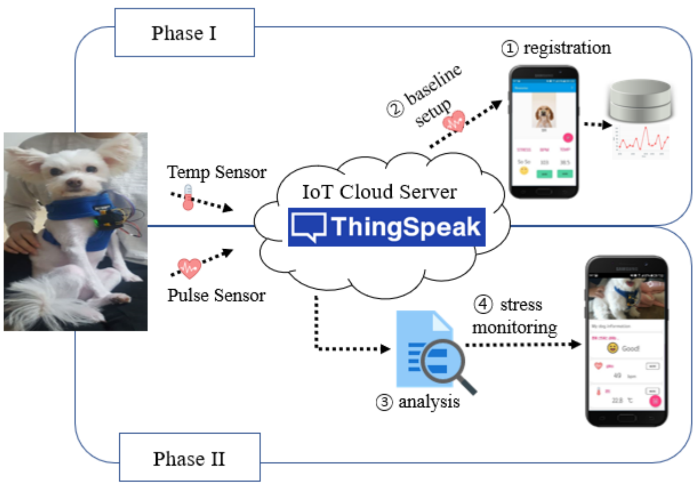


***Fig. 1**. Overall process of Bowwow system*

3 BOWOW SYSTEM ARCHITECTURE

We propose a Bowow system that can monitor the physical and mental health of dogs in real-time. Fig. 1 is showing the entire process of the proposed system. The proposed system has consisted of two stages. First, in Phase I, the dog information registration and baseline setting are performed. In other words, registering information of dogs such as profile image, name, gender, dog breeds, age, and weight, then performing work to set the baseline of the dog by measuring temperature and heart rate data when the dog is psychologically stable. Phase II consists of a dog's stress measurement and monitoring service. That is, consisted of determining the state of the dog's emotions by comparing the currently sensed data from measure the temperature and heart rate of dogs with the baseline and for the user to use the app to visually-monitor the analyzed results. The following section details the structure of the IoT device and how to set up the baseline used in the Bowow system and details the algorithms that monitor the emotional state of dogs.

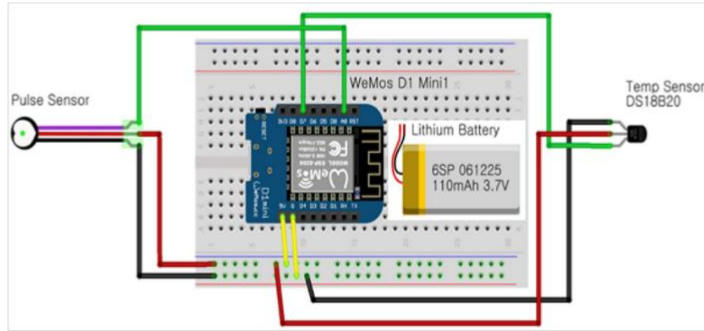


***Fig. 2**. Arduino Board composition for wearable IoT device*

***Fig. 3**. IoT Device for data collections of ECG and temperature*

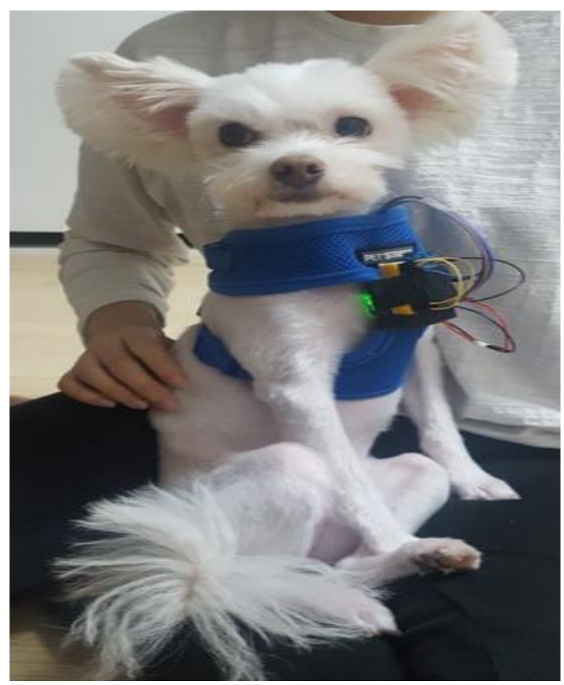


***Fig. 4**. The dog wearing IoT Device*

3.1 Design of wearable IoT Device

We first designed the IoT device to acquire the dog's heart rate and body temperature information. The device is equipped with a heartbeat sensor and a temperature sensor in Arduino

Uno mini WeMos D1 R2 equipped with a WIFI module such as Fig 2, and also consisted of a logic level converter, a lithium battery, and an LED used to convert a heartbeat sensor voltage. Also, we made an IoT device using a dog leash, as shown in Fig.3, to be not inconvenient for dogs to wear and move. When wearing this device, the heartbeat sensor should be attached that it contacts the less hairy area. Fig.4 is showing the state of the dog that attached the device. And the data sensed from this device are stored in the IoT cloud server, ThingSpeak.

3.2 Baseline Setup

The Bowow system registers basic information of dogs, and then set up a baseline of dogs. We measured the dog's heart rate for about 15 minutes with the dog in stable condition to be set the dog's baseline in healthy condition, and the measured data are used as a baseline to determine the dog's emotional state. We calculate standard deviation of normal to normal interval (SDNN) and root-mean-square of successive differences (RMSSD) from measured electrocardiogram (ECG) data and determine the emotional state of dogs based on this. The pattern of one cycle of an ECG consists of a P-Q-R-S-T wave in sequence, and the interval between R peaks is called the RR or NN interval [12].

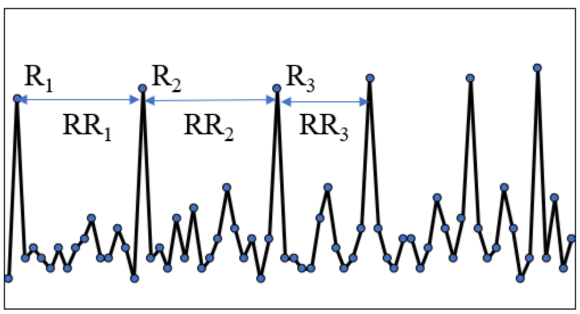


***Fig. 5**. RR interval of ECG data*

Fig.5 is showing the RR_i, which is the basis of SDNN and RMSSD. SDNN is as a standard deviation of the overall RR interval, and as an index that can measure how much the heart rate change is during the recording time, to be calculated by equation 1. If the SDNN is large, it means that the heart rate variability is so irregular, and the opposite case means that heart rate variability is monotonous. It has characteristic that the healthier, the more complex and irregular the heart rate variability, and the more stress the signal of the heart rate variability become monotony. RMSSD averages the sum of squares for differences in adjacent RR intervals, and the square root for them is calculated as shown in equation 2, and this is the indicator that well shows variable factor in heart rate over a short period.

$$SDNN = \sqrt{\frac{\sum_{i=1}^{N}(RR_i - meanRR)^2}{N-1}} \quad (1)$$

$$RMSSD = \sqrt{\frac{\sum_{i=1}^{N-1}\left((R_{i+2} - R_{i+1}) - (R_{i+1} - R_i)\right)}{N-1}} \quad (2)$$

3.3 Stress Monitoring

We evaluated the stress condition of dogs based on ECG measured in baseline data and specific situations of dogs. Algorithms 1 and 2 show algorithms for assessing stress in dogs.

Algorithm 1. CheckStress

Input : baseline, ECG

Output : stress status of dog (Good, So So or Not Good)

```
1.  RR = get IBI of baseline
2.  bSDNN and bRMSSD is array for baseline SDNN and RMSSD
3.  for(int i=0; i<RR.length; i +=wnd){
4.     bSDNN.add(calculateSDNN(RR[i:i+wnd]))
5.     bRMSSD.add(calculateRMSSD(RR[i:i+wnd]))
6.  }
7.  RR = get IBI of ECG
8.  cSDNN and cRMSSD is array for ECG SDNN and RMSSD
9.  for(int i=0; i<RR.length; i +=wnd){
10.    cSDNN.add(calculate SDNN(RR[i:i+wnd]))
11.    cRMSSD.add(calculate RMSSD(RR[i:i+wnd]))
12. }
13. sResult = CalculateStress(bSDNN, cSDNN);
14. rRssult = CalcuateStress(bRMSSD, cRMSSD);
15. if(sResult ==1 && rResult==0)
16.    return "Good"
17. else if(sResult==0 && rResult==1)
18.    return "Not Good"
19. else
20.    return "So so"
```

Algorithm 2. CalcuateStress

Input : BData, EData

Output : integer

```
1.  f = calculate number of data whose difference between BData and
    EData is no zero.
2.  plusRank = calculate sum of the plus ranks for BData and EData
    using Wilcoxon signed rank test
3.  minusRank = calculate sum of the minus ranks for BData and
    EData using Wilcoxon signed rank test
4.  if(abs(plusRank) < abs(minusRank))
5.     tScore = plusRank
6.  else
7.     tScore = minusRank
8.  cValue = get Wixcon critical value for f
9.  if (tSocre <= cValue)
10.    Return 1;
11. else
12.    Return 0;
```

We used the IBI (Inter Beat Interval) as the RR value among measured ECG data and calculated the RR value of ECG data's SDNN and RSSD as window size intervals. Then, Wilcoxon signed rank test was performed based on that. The Wilcoxon Sign test is a statistical comparison of the average of two dependent samples. Fig.6 is showing Wilcoxon signed rank test. The difference between the baseline and the newly measured data was obtained, and the signed rank was calculated after sorting the values, and the plus sum and minus sum were obtained. The absolute value among the sum compares a value with a large value to Critical T values of

Wilcoxon (95% CI), and if the value is smaller than the T value, it was represented as 1 that there is a significant change, and it was made to return 0 otherwise.

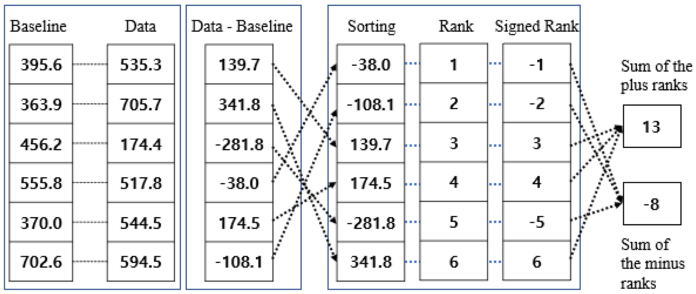
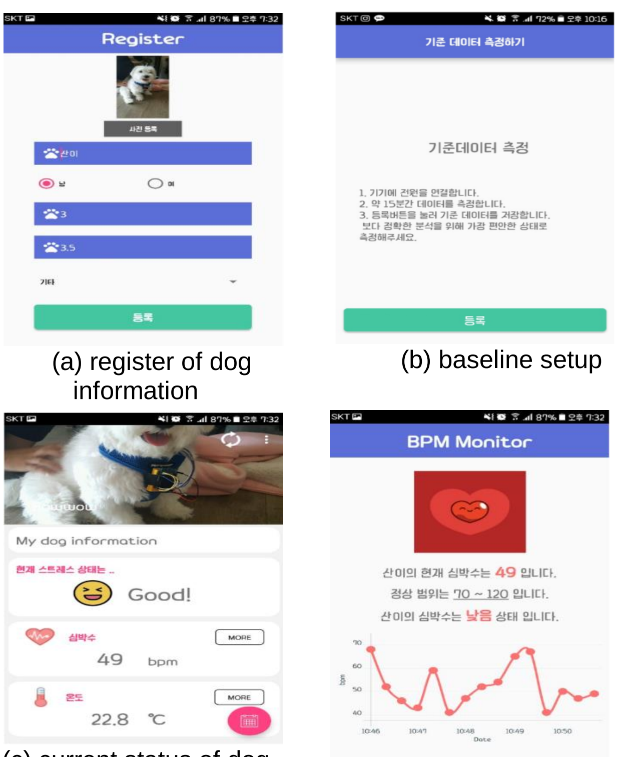


Fig. 6. Wilcoxon signed rank test

Based on these meaningful changes to SDNN and RMSSD, the design was designed to determine "Good" as a pleasant state when only SDNN changes, "Not Good" as a stressful situation when only RMSSD changes, and "So So" in addition to that.

4. EXPERIMENTAL RESULTS

Three Maltese aged 2 to 4 years participated in the experiment, and their weight was 3.0 to 3.5 kg. The dogs involved in the experiment shall register their information, as shown in (a) of Fig.7. After registration, the baseline data should be measured through a screen such as (b) of Fig.7 with the dog in a comfortable state. Once the data has been measured, this data is used as the basis for the stress assessment.



(a) register of dog information
(b) baseline setup
(c) current status of dog
(d) BPM history

Fig. 7. Screen composition of Bowwow App

After the dog baseline has been set up, a screen representing the dog's current state was configured to appear, as shown in (c) of Fig. 7. When you click the Refresh button, the dog's status can be updated at any time, and it was organized, as shown in (d) in Fig. 7 to be able to monitor changes in the dog's heart rate. In this experiment, tested how much a person's behavior or words at home, or the condition of dogs when they are alone, affected the change of the dog's emotions. In this experiment, we tested how much a person's behavior or words at home, or the condition of dogs when they are alone, affected the change of the dog's emotions. We carried out experiments on petting dogs, telling them to go for a walk, giving them snacks, playing with a toy, going around alone, and sitting still. Table 1 shows the stress measurement result according to actions.

TABLE 1

EXPERIMENTAL RESULTS FOR EVALUATING STRESS ACCORDING TO ACTIONS

Actions	*SDNN*	*RMSSD*	*Results*
Petting a dog	*8*	*10*	*So So*
Telling a dog to go for a walk	*-9*	*6*	*Good*
Giving a dog snack	*-43*	*9*	*Good*
Playing with a toy	*5*	*5*	*So So*
Going around alone	*3*	*9*	*So So*
Sitting down	*8*	*9*	*So So*

Experiment results have shown that dogs like the behavior of telling them to go out for a walk, and giving them snacks, and the behavior of such as petting or playing with toys do not have a significant effect on stress. Also, even when they are alone, the actions of the dog going around alone or sitting is not under great stress.

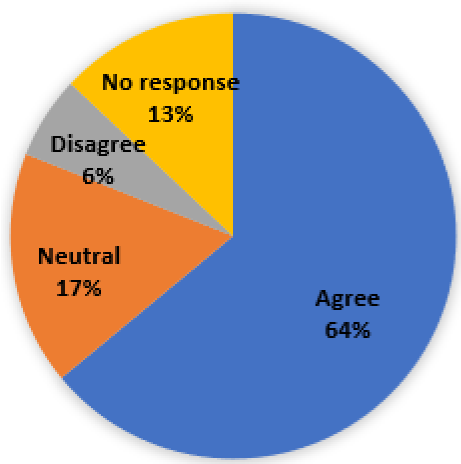


***Fig. 8**. Survey results*

To detect the usefulness of the proposed Bowwow system, we conducted a survey of 122 users, "Would it help you to understand the stress state of dogs?" The results are shown in Fig.8. 64% Of the 122 respondents said positively "yes", 17% said "Not bad", 13% said "I don't know," and 6% said "No".

IV. CONCLUSIONS

In this paper, we proposed a Bowwow system that can check the stress of companion dog at any time and place. The proposed system is a system that can provide the health status and stress level of dogs in real-time based on temperature and heart rate data from the wearable device mounted on a dog's leash. We will conduct various experiments on the behaviors we do with dogs in everyday life, targeting more dogs to promote communication with dogs.

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