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SURVEY PAPER

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Emotional studies in dogs and cats and their estimation techniques: an engineering perspective

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ABSTRACT

Dogs and cats have exceptionally developed sensory systems and abilities to recognize human signals and emotional states. It makes them invaluable in roles such as working dogs and therapy animals in human society. Understanding each other's emotional state is essential to working with them effectively. However, the low accuracy of human emotional estimation in dogs and cats is a significant issue. Due to individual differences and cognitive biases affecting human subjective assessments, automatic emotional estimation is crucial. To address this issue, there is a demand for automated emotional estimation technology. This paper provides an overview of emotional research in dogs and cats, their senses, and their roles in interaction with humans. In addition, we described automated emotional estimation technology using image/video and electrocardiography as a complement to human ability for emotional recognition of dogs and cats, and its applications for implementation. Practical implementation of automated emotional estimation technology should be adaptable to different breeds, individuals, and environmental conditions. Improving this technology has the potential to contribute to various fields, including pet welfare enhancement, veterinary care, ethology, and support for humans with dogs or cats.

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1. Introduction

There are numerous super sensors in organisms. These biological super sensors have innovated engineering technologies and contributed to the development of human society [1]. Dogs and cats possess superior sensory systems such as keen olfaction [2,3]. Moreover, through domestication, they have acquired the ability to identify signals and emotional states of humans [4]. Leveraging these abilities, they excel in roles such as working dogs and therapy animals in human society. Especially, dogs have been useful as 'co-workers' for a long time and have recently been used in various situations such as assistance dogs [5], medical detection, detection of drugs, explosives, humans and remains at disaster sites [6]. The advantages of the dog method are, especially, non-invasiveness, rapidity, immediate results, cost effectiveness, mobility, high sensitivity and specificity, and simplicity and safety of the procedure. Some research has been conducted to improve the efficiency of work by guiding dogs using sound, vibration and light [7–14]. In guiding dogs, it is important to understand the emotional states of dogs and provide commands at appropriate times. Understanding emotional states of dogs using non-invasive techniques helps in assigning appropriate tasks to them. However, humans have a limited ability to recognize the emotions of dogs and cats. To maximize their abilities, objective emotion recognition technology is necessary, built upon understanding emotional research in dogs and cats, as well as the sensory systems enabling emotional cognition between humans and these animals. However, humans have a limited ability to recognize the emotions of dogs and cats. To maximize their abilities, emotional recognition technology is necessary, built upon understanding emotional research in dogs and cats, as well as the sensory systems enabling emotional cognition between humans and these animals.

In this survey paper, first, we outline the methods used in the field of ethology to measure emotion in dogs and cats. Next, the ability to recognize emotions interspecifically between dogs, cats, and humans is described. Finally, we will introduce techniques for automatic estimation of dog and cat emotions and their applications.

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2. Animal emotion

Emotion is a brief, intense emotional response to specific events or stimuli. This is a driving force that regulates an animal's behavior to adapt to the environment. If animals do not feel fear in any situation, they would likely venture into dangerous places and risk their lives. If animals do not feel pleasure for anything, they would not be able to find food or breeding partners, reducing their chances of survival. In other words, negative emotions elicit avoidance behaviors when encountering stimuli that threaten adaptability, while positive emotions induce approach behaviors toward stimuli that enhance adaptability. Emotions have played a pivotal role in the evolution of animals.

The presence of emotions in animals was already suggested by Charles Darwin in his book 'The Expression of the Emotions in Man and Animals' [15]. There are similarities in the expression of emotions (facial expressions) between humans and non-human animals. He proposed that humans can understand the expressions of animals to some extent. Morton suggested that specific acoustic structures correspond to specific emotional states in many vocalizations of mammals and birds [16]. In addition, Evans [17] stated that emotions are not a uniquely human phenomenon but exist in various species, suggesting that emotions could be considered as a shared or invariant language transcending species. While the primary issue in the study of animal emotions remains whether emotion requires conscious experience [18], it is inferred that the expression of emotions in both humans and non-human animals is supposed to have evolutionary continuity in many aspects. The research on the emotional experiences of animals could lead to our comprehension of the evolutionary aspects of human emotions.

Dogs and cats are unique animals closely integrated into human social networks, despite differences in the sociability of their ancestors and the process of domestication [19]. The foundation of coexistence between humans and dogs, as well as humans and cats, relies on non-verbal communication, requiring the accurate interpretation of each other's expressed emotions. Dogs and cats have acquired social cognitive abilities and communication methods similar to humans, suggesting a process of convergent evolution [19–23]. There is even a suggestion that dogs have evolved specific appealing expressions for humans through domestication [24,25]. Cats have also undergone changes in facial morphology to become attractive to humans through domestication [26]. These findings indicate that dogs and cats provide unique non-primate models for studying intriguing emotional expressions.

3. Measuring emotion of dogs and cats

Emotion involves a physical response by its definition. Although the conscious experience of emotion is not directly assessed because we could not ask dogs or cats about it, the behavioral and physiological indicators that accompany emotion are measurable. It is difficult to distinguish between positive and negative emotions. For example, frustration is closely associated with the presumed positive emotional state that arises when a reward is expected [27–29]. In some species, the anticipation of positive rewards is associated with an increase in activity, which resembles the high levels of stereotypical behaviors [27,30–33]. Given that the same situation can be interpreted as eliciting both positive states and the negative emotion of frustration, it is unclear which emotion an animal exhibits in this situation. In addition, an inactivity state is generally associated with low cortisol levels, suggesting that animals are in an optimal state without stress. However, this state may also arise from learned helplessness, a perception that any action is futile. From these observations, it has been suggested that determining whether an emotion is positive or negative based on a single indicator is challenging, and a more beneficial approach involves the composite use of behavioral, physiological, and neurological indices. The following section introduces emotional research that utilizes behavioral, physiological, and neurological indicators (Figure 1).

3.1. Behavioral indicators

3.1.1. Behaviors, postures and facial expressions

Research on the emotional aspect of fear in animals traces back to studies by Solomon and colleagues on avoidance conditioning in dogs [34,35]. These studies involved pairing a buzzer sound with an electric shock to induce avoidance behaviors, resulting in observable emotional reactions such as defecation, urination, yelping, and trembling, indicative of fear in dogs. Presently, research predominantly involves exposing animals to stimuli expected to elicit fear and observing their behavioral responses [36,37]. Leyhausen's work provided insights into cat's emotional states through careful observation of behaviors and facial expressions [38]. Additionally, the open-field test, commonly used in rodents, has been adapted as an experimental model to measure fear and anxiety in cats [39]. In veterinary practice, emotional states of dogs and cats are inferred from observed behaviors and postures [40–45]. Furthermore, research indicates lateralization of emotion processing in the brain of dogs and cats, with behaviors and facial expressions such as wagging of a tail, movement of eyebrows and usage of nasal cavity [46–52]. In the twentieth

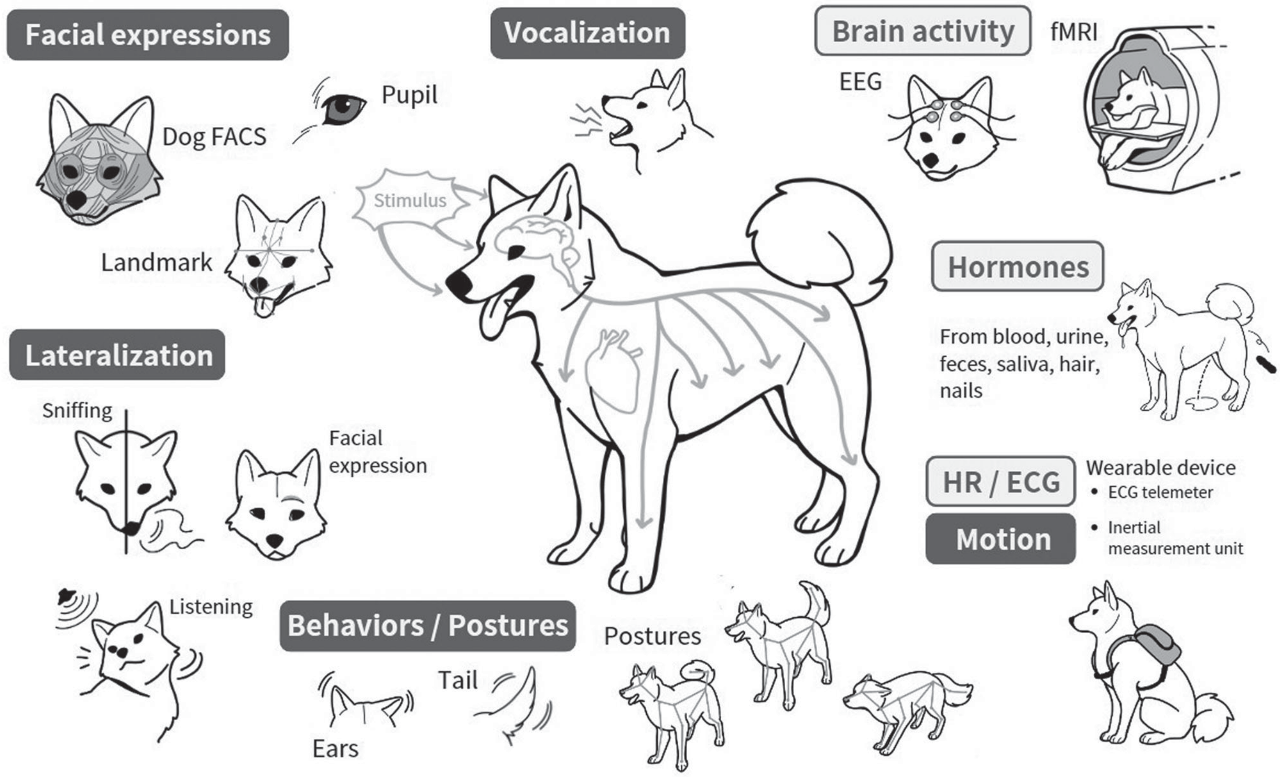

Figure 1. Summary of major methods for measuring dog emotions. Behavioral indicators are color-coded in dark-grey and physiological indicators in white. Behavioral indicators include facial expression by the dog facial coding system (DogFACS), landmarks and pupils, lateralization, vocalizations, behaviors/postures, and motion. Physiological indicators included brain activity by electroencephalography (EEG) and fMRI (functional Magnetic Resonance Imaging), hormones, heart rate (HR) and electrocardiogram (ECG).

century, the field of expression research advanced with greater precision by Ekman's Facial Action Coding System (FACS), which allowed for the systematic encoding of facial movements [53]. Facial expressions are encoded into machine-discernible forms by combinations of the presence or absence of various facial muscle movements known as action units. This system has been adapted to various species, leading to the development of DogFACS [54] and CatFACS [55]. Through DogFACS, it became possible to distinguish between positive expressions associated with the anticipation for rewards and expressions of frustration, previously considered challenging to differentiate [56,57]. In the case of cats, a correlation analysis between emotional behaviors and CatFACS was conducted [58], leading to the classification of three emotions: relaxation, fear, and frustration. Associated facial expressions corresponding to these emotions were identified. Furthermore, studies employing the landmark method have been conducted [59]. Seventy-eight facial landmarks were placed on the cat's face based on anatomical knowledge, and 80 measurements based on anatomical knowledge were collected and analyzed. These measurements helped identify pain expressions in cats with 98% accuracy.

3.1.2. Vocalizations

Vocalization has proven to be highly valuable as indicators of emotional states. Given the similarity in vocalization mechanisms between humans and other mammals, changes in vocal parameters responsive to emotional states can be similarly interpretable [29,60,61]. Physiological phonetics is fundamentally explained by the Source-Filter Theory [62–64]. In this theory, the energy from exhaled air from the lungs is used to create the sound source (source) by the vocal cords. The resulting sound is then modified (filtered) through resonance in the vocal tract. The source determines the fundamental frequency (F0) of the vocalization, while the filter selectively amplifies certain frequencies and attenuates others, shaping the sound signal. In emotional correlation research, various indicators such as vocalization frequency, duration, inter-vocalization/element interval, F0 contour (the sequence of F0 values across the vocalization, including F0 mean, start, end, minimum, maximum), F0 range, peak frequency, among others, are considered valuable [65].

Studies investigating the relationship between emotions and vocalizations in laboratory or captive animals, similar to expression research, are conducted by placing the animals in situations believed to evoke various arousal levels and emotions. Several studies have demonstrated that dogs and cats produce acoustically distinct vocalizations in response to each situation [66–75]. For example, while individual variation in dog barking is significant, they exhibit distinct frequencies and barking durations in three situations (unfamiliar human, isolation, playing) [69]. In addition, the same category of vocalization 'meows' in three different situations to elicit different emotional states (waiting for food, isolation, brushing) exhibit distinct spectrograms [73]. It is considered that the differences in motivation for each situation are reflected in the vocalizations.

3.2. Physiological indicators

Physiological and neurological research on negative emotional states, such as those associated with stress, has been extensively conducted. Two primary systems that respond to environmental stimuli that is 'stress' are the hypothalamic–pituitary–adrenal (HPA) axis and the autonomic nervous system. Various indicators such as glucocorticoids, which are the end products of the HPA axis, as well as parameters controlled by the autonomic nervous system like blood pressure, heart rate, and body temperature, have been used.

3.2.1. Hormones

Hormones support the maintenance of homeostasis in response to stimuli. Cortisol, one of glucocorticoid, is an essential hormone for the body that regulates metabolism. It is released in response to environmental stimuli and elevates blood pressure to prepare the body for the fight or flight response. Cortisol is a circulating hormone in the bloodstream and can be measured in various biological samples such as blood, urine, feces, saliva, hair, nails, earwax. Particularly in the field of animal welfare, there has been numerous research on the relationship between negative states and cortisol [37,76–82]. Generally, low cortisol levels are interpreted as indicating a low-stress state, meaning not in a negative state. However, it's important to note that low cortisol levels do not always indicate a positive state. As mentioned earlier, low cortisol levels can also be expected in cases of learned helplessness, so interpretation should consider multiple indicators.

Additionally, recently, oxytocin has been used as an indicator of positive emotional states. When dogs were placed in situations believed to induce positive emotional states, such as meals, exercise, or being petted, they showed an increase in oxytocin levels in their blood, urine and saliva [83–85]. On other hand, in the case of cats, oxytocin levels were higher in non-social interaction conditions compared to social interaction conditions with humans [86]. Oxytocin is also associated with anti-stress and anxiety-reducing effects, so it cannot be unequivocally equated with a positive state solely based on its levels.

Although hormones can indeed be measured from various biological samples, it should be noted that there are different collection times and sample types suitable for different hormones. For instance, cat's plasma cortisol increases after 15 min following stress stimuli and returns to baseline after 90 min [87]. In addition, exogenous oxytocin administration through a venous catheter can be reflected in urine samples approximately 30 to 90 min later [84]. Hair is considered suitable for measuring long-term emotional states because it accumulates hormones over an extended period.

3.2.2. Heart rate, heart rate variability (HRV) and electrocardiogram (ECG)

The activation of the sympathetic branch of the autonomic nervous system can be captured by an increase in heart rate, defined as the number of heart beats per minute (bpm) recorded [88]. This indicates the onset of physiological stress response and heightened psychological arousal which is a state of increased emotional activity [89]. In addition, variability in heart rate, specifically changes in the time intervals between heartbeats, is suggested to reflect the balance of regulation between the sympathetic and parasympathetic branches of the autonomic nervous system. Indicators of the heart rate and sympathetic and parasympathetic nervous systems based on HRV analysis have been used for emotion estimation in dogs and cats [36,90–100]. Katayama et al. showed the usefulness of HRV indicators from ECG in distinguishing between positive and negative emotions in dogs [100]. There are various techniques for measuring heart rate, including implanted radio-transmitters, wearable heart rate monitor, non-contact monitoring using millimeter wave radar and more. In the case of dog experiment, wearable heart rate belts are commonly used.

3.2.3. Electroencephalography (EEG)

EEG is a recording of the electrical activity generated by the brain of animals. EEG is primarily used as a diagnostic tool in clinical settings for epilepsy research [101,102]. Previous EEG research involving animals has been mostly invasive, often requiring sedation or anesthesia, which can affect cognitive processing. Recently, non-invasive methods have been applied to dogs. However, various factors such as eye movement, blinking, respiration, and muscle tension can introduce artifacts into the EEG recordings. This necessitates time and effort consuming training to ensure that the dog remains relaxed and still while electrodes and wires are attached. Through non-invasive EEG in dogs, researchers are starting to uncover the brain activity of dogs when presented with emotionally engaging stimuli [103,104].

3.2.4. Functional magnetic resonance imaging (fMRI)

fMRI captures changes in MR signals resulting from blood flow changes related to brain activity, allowing researchers to determine which brain regions are activated, that is, which areas of the brain are active. Recording brain activity related to emotions in an awake state typically requires training animals to remain calm and still in a closed space with noise. This is difficult for cats but has been recently conducted with dogs [105–113]. When exposed to videos expected to evoke a particular emotion, such as watching their owner interact with another dog, dogs have shown activation in the amygdala, insular cortex, and hypothalamus [110]. Additionally, when viewing videos of giving the other dog food, amygdala activity was observed [107].

3.2.5. Other indicators

Various indicators controlled by the autonomic nervous system have been used for estimating the emotional states of dogs and cats, among other methods. Examples of such indicators include skin temperature [114–120], respiratory rate [121–123], and eye activity including blinking [124,125]. Recently, it has been suggested that tear production in dogs may also be an indicator of positive emotional states, as tear production increases when reuniting with their owners than familiars [126].

4. The ability of dogs and cats to perceive human emotions

The significance of expressing and perceiving emotions lies in the adaptive behavior achieved by detecting the emotions expressed by others and adjusting one's own behaviors accordingly. The ability to detect changes in the environment quickly through the emotional expressions of others allows one to adapt to those changes. By recognizing the negative emotions of others, one can fade in the distance from potentially dangerous situations, while recognizing positive emotions may lead to opportunities for reward acquisition. Despite being different species, dogs and humans, as well as cats and humans, form social groups and interact closely. For them, one of the 'others' is the human. Approaching an angry human may result in negative consequences, while approaching a cheerful human may lead to receiving treats or experiencing positive outcomes. In this section, we first describe the dog's and cat's visual, auditory, and olfactory senses, which are the basis of emotional cognition, and how these senses are utilized in their relationships with humans.

4.1. Sense of dogs and cats

4.1.1. Visual

Visual system experts describe dogs as visual generalists, suggesting that a dog's eyes are designed to function in a wide range of situations [127]. Relative to other conditions, the visual systems of dogs and cats function effectively in low light levels, and they are particularly sensitive to the movement of objects. Dogs and cats have been shown to have lower spatial frequency resolution (cycles per degree) for visual acuity compared to humans [128,129]. This means that humans can recognize objects from roughly three times the distance compared to dogs and cats. In terms of color vision, dogs and cats lack the ability to discriminate between wavelengths in the medium to long range, making them dichromatic, while humans have trichromatic color vision [130,131]. While the human eye's lens blocks ultraviolet light, in animals with ultraviolet-transmitting lenses, ultraviolet light reaches the retina. The retina then converts light into neural signals that reach the brain for visual processing. The research has suggested that dogs and cats have lenses that transmit ultraviolet light, implying that they can perceive ultraviolet light [132].

4.1.2. Auditory

One of the anatomical features of the ears in dogs and cats is the pinna, which can be moved toward the sound source to help absorb sound more effectively. their audible range is wider than that of humans. Many mammals, including dogs and cats, can hear higher frequencies than humans [133–135]. Among mammals, where many have lost their ability to hear low frequencies, cats stand out as being capable of hearing low-frequency sounds as well [134].

4.1.3. Olfactory

Their sense of smell is highly developed, capable of detecting even trace amounts of chemical substances. Anatomical research has revealed that dogs and cats have a nasal structure characterized by long, coiled passages within a limited space, which provides a large nasal mucosal surface area [136,137]. This structure is suggested to function in a manner similar to a gas chromatograph. While the nasal mucosal area in cats is about half that of dogs, it is approximately five times greater than that of humans [137]. Additionally, dogs and cats possess the vomeronasal organ, which has become vestigial in humans. The vomeronasal organ is specialized for detecting species-specific chemosignals, such as sex pheromones Kokocińska-Kusiak and his colleagues have extensively documented the sense of smell in dogs [138].

The noteworthy aspect here is the phenomenon of lateralization of olfaction. Initially, there is a right nostril bias, and subsequently, when exposed to non-aversive odors such as something familiar, the dog starts to use the left nostril [49]. However, when confronted with threatening or excitatory odors, the dog continues to use only the right nostril. These findings are analogous to visual and auditory channels [47,48]. These findings can be explained by the theory reviewed by Vallortigara et al. that the right hemisphere controls novel information processing, the left hemisphere is responsible for behavioral responses to familiar stimuli, and the right hemisphere maintains dominance over the sympathetic-hypothalamic–pituitary–adrenal axis [139,140].

It's important to consider differences in these senses related to size and breeding. Additionally, the environmental factors, such as humidity and temperature, can also affect the perception of them. In any case, it's important to note that humans and dogs or cats have slightly different sensory organs, leading to distinct perceptual worlds for each of them.

4.2. The role of visual, auditory, and olfactory senses in dogs' and cats' recognition of human emotions

They communicate with humans through visual, auditory, and olfactory signals. These senses, needless to say, play a crucial role in perceiving human emotions. They are sensitive to human facial expressions and accompanying postures [141–144]. Nagasawa *et al.* indicated that dogs can distinguish between their owners' neutral faces and faces with smiles, as well as same-sex humans' faces with smiles by a two-choice task [143]. Another study investigated the behavior of dogs toward three human facial expressions (angry, neutral, smiling) [143]. They compared the proportion of dogs following the pointing gestures of humans displaying each facial expression and the proportion following neutral cues. The results showed that dogs were significantly less likely to follow the pointing gestures of individuals with angry or neutral facial expressions compared to following neutral cues. However, when a person displayed a smiling expression, dogs were as likely to follow their pointing gestures as they were to follow neutral cues. Galvan and Vonk investigated the behavior of cats toward humans displaying angry expressions and postures compared to humans displaying positive expressions [144]. The results showed that cats exhibited behaviors such as approaching humans displaying positive emotions rather than those displaying expressions of anger. In summary, dogs and cats engage in emotion recognition through visual cues and respond with appropriate behaviors.

They also exhibit different responses to human emotional vocalizations. Siniscalchi et al. recorded the responses of dogs when exposed to several human vocalizations [145]. Through the analysis of head orientation, they found that vocalizations associated with negative emotional valences such as fear or sadness were often processed more in the right hemisphere, while vocalizations linked to positive emotions like happiness were frequently processed in the left hemisphere. Furthermore, heart rate and behavior also exhibited different responses based on human emotion. While there is currently no cat research examining the responses to only human vocalizations with emotional expressions, it has been demonstrated that cats can alter their responses based on auditory and visual emotional cues from humans. Social referencing, in which individuals observe and adjust their behavior based on the attitudes of their caregivers toward unfamiliar stimuli, is observed in both dogs and cats [146–148]. When dogs or cats witness their owners interacting with unfamiliar stimuli positively, they tend to exhibit positive attitudes, whereas negative interactions from their owners may lead to negative attitudes in response to the same stimuli. In addition, they integrate human visual and auditory emotional cues cross-modally [144,149].

Their sense of smell is also useful in emotional recognition. Dogs exhibited significantly different behaviors and heart rate to the odor of human sweat when individuals had watched videos inducing fear or happiness [150]. In addition, the combination of sweat and breath odor from individuals was shown to distinguish between when they were under stress and their baseline odor [151]. For cats, the human odor of fear-induced higher stress levels than the odor of physical stress or neutral conditions, and with the increase in stress levels in response to the human odor of fear, the right nostril was used more frequently (indicating activation of the right hemisphere) [152]. Dogs' sense of smell allows them to detect not only emotions but also various medical conditions and disease, such as seizures [153–163]. These abilities are believed to be due to differences in the components of volatile organic compounds (VOCs) released from human breath, skin, urine, feces, and saliva. These findings suggest that dogs can detect changes in human VOCs associated with acute psychological stress.

5. The ability of humans to perceive dogs' and cats' emotions

The emotional recognition of dogs and cats by humans based on facial expressions and vocalizations is influenced by experience, but the accuracy of this recognition is generally low [164–167]. Research conducted by Horowitz prominently demonstrated the misinterpretation of dog expressions by humans [168]. The emotional attribution commonly made toward dogs, known as the 'guilty look,' suggests that dogs feel guilt when they engage in prohibited behaviors. The owner instructed the dog not to eat a treat and then left the room. During this time, experimenters manipulated whether the dog complied with or violated the instruction. If the dog violated the instruction, the owner scolded. The behavior of displaying a guilty expression, regardless of whether the dog followed the instruction, was triggered by the scolding from the owner, who believed the dog had not complied with the instruction. Only 13% of participants were able to correctly identify whether a cat was in pain or not, achieving an accuracy rate of over 80% [59]. When participants were asked to make a binary choice of whether the cats in short video clips displayed positive or negative emotions, the average score was low at 11.85 out of 20 points [169]. Only 15% of participants were able to correctly identify the emotional state of the cats in 15 or more out of 20 questions [169].

There have been studies where auditory information, expected to contain emotional cues from dogs and cats, was presented to humans [67,73,170–173]. In a study where humans were asked to identify various situations based on dog barks (such as barks when directed at unfamiliar humans, when going for a walk, when alone, or when playing), participants achieved accuracy rates higher than chance levels. However, the accuracy rates were around 40% regardless of whether the participants were dog owners or not. Similarly, in the case of cats, when humans were asked to identify meowing in different situations (when they wanted food, during isolation, or during brushing), participants did not significantly surpass chance-level accuracy in any of these contexts [73]. When it comes to identifying the context of their own pet cat's meowing, humans achieved accuracy rates higher than chance levels but still around 40% [172]. Studies on whether humans can identify the emotional expressions of dogs and cats have been conducted extensively. However, the results consistently show that humans do not achieve high levels of accuracy in these tasks. In addition, evidence from heart rate variability analysis also suggests that dog owners may not be very sensitive to signals from their dogs [174]. During the Strange Situation Test, when dogs engage in attachment behavior by looking at their owners, there is a decrease in parasympathetic nervous system activity. However, the parasympathetic nervous system activity of the owners remains unchanged, suggesting a potential lack of awareness of signals from the dogs.

One of the reasons for the mismatch in human recognition of emotions in dogs and cats is that humans, when observing emotional expressions in different categories such as humans and dogs, may be inadvertently missing crucial emotional cues that are significant for dogs due to applying the same gaze patterns [175]. According to this research, when viewing emotional expression videos, humans focused more on the faces rather than the bodies in both human and dog videos. Despite significant differences in appearance and behaviors across species, humans tend to adopt similar visual strategies when observing different species and often treat them in a human-like manner [176,177]. This tendency makes it difficult for humans to accurately discern emotional expressions in dogs and cats.

6. Automatic emotion estimation technology

Recently, breakthrough technologies for estimating the emotions of dogs and cats have been developed. The instant automatic emotion estimation technologies enable smoother and effective interactions between humans and dogs or cats. In this section, we introduce the examples of emotion estimation technology for dogs.

6.1. Dog automatic emotion estimation using image/video

Various studies have been conducted using behavioral approaches to estimate dog emotions. In many cases, evaluation of dog behavior and emotion is done visually by the experimenter, but such cases may lack appropriate quantitativeness and reproducibility. In order to solve this problem, it has been proposed to apply deep learning methods to images or videos to estimate dog emotions. In the following part, we introduce these methods and summarize them in Table 1.

6.1.1. DeepLabCut

DeepLabCut (DLC) is a deep learning method for markerless pose estimation from videos of animals performing various actions [178]. DLC provides pre-trained models to estimate the posture of quadrupeds, dogs, cats, and other animals. Ferres et al. used DLC to estimate dog posture and utilized the results to predict dog emotion [179]. In their method, the emotion detector used the coordinate data detected by DLC. They developed several models to determine a dog's emotional state such as 'Anger', 'Fear', 'Happiness' and 'Relaxation', with accuracies ranging from 60% to 70%. The results also showed that the tail was important for the estimation.

Table 1. Overview of automatic emotion estimation from images.

	DeepLabCut	DINO-ViT	WS-DAN
Purpose	Markerless pose estimation	Classification and others	Classification
Characteristics	GUI annotation tool available	- Image Encoder[a] - self-distillation with no labels	- Object Localization - Data Augmentation
Input	Image/video	Image	Image
Pretrained model	- SuperAnimalQuadruped[b] - full_dog (currently not supported)	Trained with ImageNet-1k[c]	Trained with Stanford Dogs[d]
Attention	NOT included	Included	Included
Previous studies applied to emotion estimation	Ferres [179][e]	Boneh-Shitrit [183]	Kubo [185]
Number of emotion classes	4 (Anger, Fear, Happiness, Relaxation)	2 (negative, positive)	3 (happy, puzzled, sad)
Classification accuracy	60–70%	89%	80–90%

[a]It encodes an image into a low-dimensional feature vector.
[b]https://deeplabcut.github.io/DeepLabCut/docs/ModelZoo.html.
[c]https://github.com/facebookresearch/dino.
[d]https://github.com/wvinzh/WS_DAN_PyTorch.
[e]Classifier used in conjunction with emotion estimation.

6.1.2. DINO-ViT

Combining self-DIstillation with NO labels (DINO) [180] and Vision Transformers (ViT) [181], a model called DINO-ViT is proposed. The ViT is an extension of the transformer model to image classification. The code is available from https://github.com/facebookresearch/dino. A pre-trained model by ImageNet [182] is also available. As an application to dogs, Boneh-Shitrit et al. used DINO-ViT to analyze emotions focusing on the facial expressions of dogs [183]. The breed of dog was fixed to Labrador Retriever, and videos annotated with respect to the types of emotion, negative or positive, were used. The video is converted to still images, and images of the dog's face were input to DINO-ViT as the dataset. Results showed that DINO-ViT had better performance in emotion classification than other methods, for example, self-supervised learning using ResNet. The results also suggest that DINO-ViT's attention is oriented toward facial parts such as dog eyes, ears, and nose.

6.1.3. WS-DAN

Weakly Supervised Deep Attention Network (WS-DAN) is a type of deep learning model that uses weakly supervised learning and data augmentation [184]. WS-DAN has two features: one is a method called object localization with attention maps. Note that attention maps represent discriminative parts of the object. The other is data augmentation using the attention map. This data augmentation is subdivided into two types: attention cropping and attention dropping. Attention cropping uses the attended region, which is the part of the image that is of most interest to the model and contains the most information. Attention dropping removes a portion of the attention region so that the model does not learn to rely on specific features of the image. Kubo *et al.* reported an application of WS-DAN for emotion estimation of a dog [185]. There were eleven emotion labels such as 'happy' and 'surprised' for the video data. The three labels 'happy,' 'puzzled,' and 'sad' with the top 3 frequencies were selected as the classification target. From the 54 videos, 7,770 still images were cut to make an image data set. The result showed an accuracy of 80.33%, and the attention map showed high attention to the dog itself. These results suggest that the performance was not affected severely by the background information thanks to the attention mechanism of WS-DAN and that this method could have high generalization capability.

6.2. Dog automatic emotion estimation using ECG

In addition to behavioral assessment [186,187], approaches from fields such as endocrinology and physiology [100,188–192] have been introduced and are used for automatic emotion estimation of working dogs. In the following part, we introduce these methods.

6.2.1. ECG measurement of dog

Wearable electrocardiography has been proposed for ECG measurement of active dogs [189,193–196]. In these studies, soft and hard disposable electrodes were brought into close contact with the body of canines by using a jacket, a harness, and a strap. Three types of leads (M-X lead, L-R lead, A-B lead) are used for dog's ECG measurements. ECG data by M-X lead is smaller fluctuation than A-B lead [194]. 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 HRV to reduce breathing noise [100,189,193].

6.2.2. Emotion estimation from HRV

It is expected to develop a method for emotion estimation using HRV. HRV is an important bio-signal that indicates the emotional state and is used to evaluate the state of the autonomic nervous system in humans [197] and dogs [198]. It is used to evaluate the states of the sympathetic and parasympathetic nervous systems, which are associated with emotion [199,200]. Many studies have focused on the relationship between a dog's HRV and emotional responses such as empathy [201], anxiety [202], aggressiveness [203], and positive/negative emotions [100].

6.2.3. Emotion estimation of a search and rescue (SAR) dog from HRV

There is a study to automatically estimate emotions using HRV calculated from ECGs of a SAR dog in action [189]. Random forest was used for automatic positive/negative emotion estimation. Japan rescue dog association certified a SAR dog was used to visualize changes in positive/negative emotions while searching for victims. Positive emotions were observed when floating odors and victims were found. By looking at the positive/negative emotions, a third party other than the handler can confirm with the data that a SAR dog is aware of the victims' odor.

6.3. Prospective of automatic emotion estimation

As described above, image/video processing methods for dogs are also being actively developed. Although DLC is not limited to dogs, it has been developed not only for two-dimensional information in a single image, but also for estimating three-dimensional positional information using multiple cameras and for tracking other animals. In the future, the development and application of similar processing technologies to dogs will be promoted further. However, these technologies can only estimate posture, and they do not yet provide a sufficient solution to the question of how behavior should be described. In the future, it will be necessary to go beyond posture to automatically evaluate more complex expressions of movement and behavior. There are still many unknown aspects of dog behavior, and there is room to discover new behaviors and redefine various behaviors in a data-driven manner through video recording and analysis under various conditions with many individuals and for long periods of observation. It is expected that through the development and analysis described above, the secrets of dogs' advanced social cognitive abilities and skills will be further unveiled, and both humans and animals will become more fulfilled with each other.

In addition, multimodal estimation of emotions is expected to improve reliability and adapt to the complexity of emotions. In human emotion research, Masui *et al.* [204] and Gonçalves *et al.* [205] both found that combining multiple indicators led to more accurate assessments of emotional states. Even when one indicator is susceptible to external environmental factors, other indicators can complement the information and provide more reliable emotion estimation. It is expected that the technology to estimate emotions by multiple indicators is used for dog emotion estimation as well, such as combinations of ECG data and behavioral data. In the last few years, monitoring using multiple indicators in dogs has also been developed. There are monitoring systems based on emotional estimation by ECG and evaluation of reliability by acceleration for SAR dogs [206]. A diagram of automatic emotion estimation is shown in Figure 2. The same principle can be used to build systems for other applications of automatic emotion estimation. It has also been reported that ECG data can predict some outcomes of the performance of guide dog puppies in the Guiding Eyes' temperament test [196]. It has been suggested that research on emotion estimation may lead to performance evaluation of working dogs. In the application of automatic emotion estimation with HRV for SAR dogs [189], a distinct emotion, positive/negative emotion, was estimated. On the other hand, emotions in the search

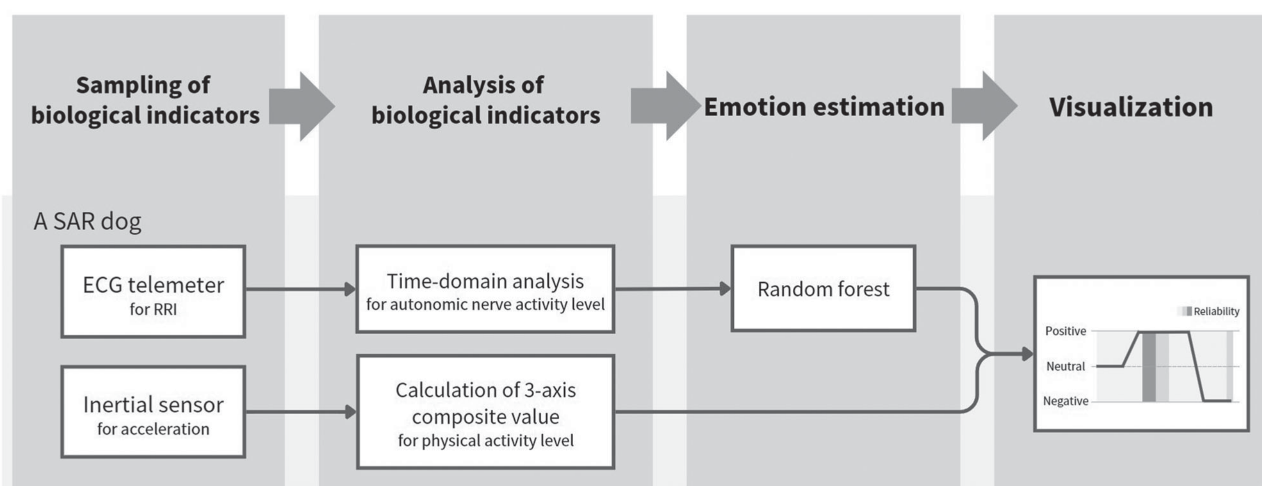

Figure 2. Diagram of automatic emotion estimation for the example of a search and rescue (SAR) dog. The RR intervals (RRI) by electrocardiogram (ECG) telemeter and 3-axis accelerations by inertial sensor were acquired to analyze the level of activity and activity level of the autonomic nervous system, respectively. Subsequently, emotions of a SAR dog were estimated, automated and visualized.

for SAR dogs are more complex. When a SAR dog is engaged in rescue, many emotions are observed, such as fear, confusion, hesitation, etc. If these emotions can also be automatically estimated, it will assist handlers in making appropriate decisions.

7. Conclusion

Automatic emotion estimation for dogs and cats is widely desired in various situations. Some automatic estimation technologies are being developed using images and heart rate variability indices. Ideally, there should be a context-specific model or a universal model capable of adapting to different breeds, size and various environmental conditions. Especially in dogs, anatomical differences based on breeds and sizes have a significant affect emotional expression. Additionally, a multimodal approach using behavioral indicators and physiological indicators is likely to provide a more comprehensive and accurate estimation of emotions. Despite some challenges, advances of non-invasive automatic emotion estimation technologies based on the specific characteristics of their emotional expressions help to provide commands at appropriate timings. It leads to effective interaction between humans and dogs/cats and optimizing the efficiency of 'co-workers.'

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