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Non-contact respiratory measurement in a horse in standing position using millimeter-wave array radar

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ABSTRACT. This study aimed to apply radar technology to a large quadruped animal. We first developed a non-contact respiration measurement system using millimeter-wave array radar for a horse in standing position. Specifically, we measured the respiration of a stationary domestic horse in stables. Simultaneously, we measured the respiration rate using infrared thermography and developed a method for analyzing the radar information while verifying the rate of agreement. Our results suggested that the radar technology detected breathing and accurately measured the respiration of a horse, despite variation in the breathing frequency. To the best of our knowledge, this is the first study to apply a non-contact respiration measurement system using millimeter-wave array radar has been applied to large animals in an upright position, thereby demonstrating its potential application in animal husbandry and welfare.

KEYWORDS: animal welfare, millimeter-wave array radar, quadruped animal, respiration rate

Respiration is a vital sign and one of the most essential criteria for health monitoring. Wearable devices have been developed to measure respiration in animals [11]. They are superior in that they can accurately measure respiration rates. However, wearing the device itself can be a stressor to the animal by reducing mobility and that the animals themselves might remove the device. Additionally, anesthesia is required for large animals that are not familiarized with humans and need to wear a device. Anesthesia is burdensome for the animal and carries a risk of mortality owing to complications. Anesthesia in non-human animals is not completely safe, and the risk of death from anesthesia is particularly high in horses (1.4–1.9%) compared with 0.17% in dogs [8]. Non-contact health monitoring is not only a stress and zoonosis control measure [4, 10] but also reduces the impact of monitoring on target animals, such as horses, which are at high risk owing to anesthesia.

One technology that can be used to obtain vital information in a non-contact manner is radar technology [9]. Because microwaves and millimeter waves can penetrate clothing and body hair, radar technology is one of the most valuable methods for monitoring respiration, involving movement of the body surface. The ability to estimate the respiration rate by radar would simplify routine health monitoring, including observations at night. Non-contact vital sign monitoring by radar is a technology that enables the conscious management of animal welfare of farm animals in the livestock industry, where there is a concern about a decrease in the number of bearers. In recent years, radar technology has been used in humans as well as pet dogs and cats to measure respiration rates remotely and accurately [3, 12, 13]. However, this technology has been applied only when the subjects were in a lying down or sitting posture. To the best of our knowledge, there has been no attempt with quadruped animals such as horses and cows that often stand on all four legs and might also sleep in that position. Therefore, it is not yet known to what extent body swaying by standing on all four legs affects the detection of breathing associated with body surface movements.

This is a pilot-study to measure respiration in large quadruped animals using millimeter-wave array radar. Simultaneously, we measured the respiration rate using infrared thermography, which is a conventional method of respiratory estimation established in humans [1], and developed a method for analyzing the radar information while comparing the rate of agreement. To our knowledge, for the first time, a non-contact respiration measurement system using millimeter-wave array radar has been applied to large animals in an upright position, indicating the possibility of its application in animal husbandry and welfare.

The subject was a horse belonging to the Equestrian Club of Kyoto University [name: Canberra, date of birth: September 7, 2001,

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sex: male (castrated), breed: Thoroughbred]. We conducted two experiments: The first was conducted at approximately 9:00 am in March 2021, when the horse had not engaged in any exercise prior to the experiments since morning of the same day and was measured while idle in the stables of the Equestrian Club of Kyoto University, and the second was conducted at 10:30 am the same day as the first. The location of the radar equipment and the thermal imaging camera were identical in the two experiments. According to the Japan Meteorological Agency, the temperature at the approximate time of the test was 9.3°C, measured at an observation point 5 km away from the test location.

Respiration was measured from a distance of approximately 1.5 m using a radar device. The radar system has a multiple-input and multiple-output (MIMO) antenna array composed of three transmission antennas and four receiving antennas (See Supplemental Information for details). The radar system used in this study captures the movement of the body surface associated with breathing. The position of the radar was adjusted so that the radar captured the lateral part of the horse's body.

Simultaneously, a thermal imaging camera was used to capture images from a distance of approximately 3 m (Fig. 1). Temperature measurement was conducted non-invasively using an infrared thermal camera (T650sc, FLIR Systems Japan K.K., Tokyo, Japan), with a resolution of 640 × 480 pixels and a frame rate of 3.75 Hz (Fig. 2). If the position of the nose is set as the Region of Interest (ROI) in the 2D measurement of infrared thermography and the decrease in temperature of the body surface is measured continuously, the timing of respiration can be detected. To track the movement of the nose, i.e., ROI, we used DeepLabCut [5, 7]. We selected the tip and bottom of the nose and both ends of the harnesses (p1–p4) as the tracking target points. The respiration pattern is calculated using temperature data in the area enclosed by p1, p2, p´3, and p´4 (Fig. 2; see Supplementary File for details).

This study was performed in accordance with the guidelines for proper conduct of animal experiments of Science Council of Japan. All experimental protocols were approved by the Animal Experimentation Committee of the Wildlife Research Center, Kyoto University (WRC-2021-007A).

The estimation results of the first and second experiments are shown in Figs. 3 and 4, respectively. In the first experiment, the horse was stable and the respiration rate was also stable for 240 sec. The respiration analyzed by radar and thermography were 17 and 16 cycles, respectively. Except for one discrepancy between the results of the two analyses caused by the counting of a small wave captured by the radar at approximately 50 sec, there was a one-to-one correspondence between the respirations analyzed by the radar and thermography. In the second experiment, the respiration rate was unstable and the spontaneous body movement of the horse was larger than that of the first experiment. The respiration analyzed by radar and thermography were 29 and 28 cycles, respectively. As in the first experiment, although there was essentially a one-to-one correspondence between the respiration analyzed by radar and that by thermography, there was a discrepancy between the results of the two analyses approximately 50 and 75 sec. A qualitative analysis of the video recording of the area where the discrepancy between the breathing rates was observed using the radar and that from the thermal imaging camera revealed that the horse was shaking its body at the time of the test.

The root mean square error between the respiratory timing measured using the thermal imaging camera and the respiratory timing obtained from the radar was 2.5 and 0.93 sec in the first and second experiments, respectively. The error was calculated as the difference between the respiratory timing obtained from the radar and the closest respiratory timing obtained using thermography.

The respiration rate of the horse in the present study was approximately 8–16 breaths per minute. We confirmed that the radar technology used in this study detects breathing, even when the frequency of breathing varies. Horses have excellent locomotion. When respiratory insufficiency occurs, their motor skills are reduced and they experience shortness of breath. Respiratory failure or impairment causes severe discomfort in humans and is believed to have similar effects in several mammals, including horses [6].

Fig. 1. Photograph of the experimental environment. The gray arrows indicate the radar device. The dotted arrow indicates the thermal imaging camera.

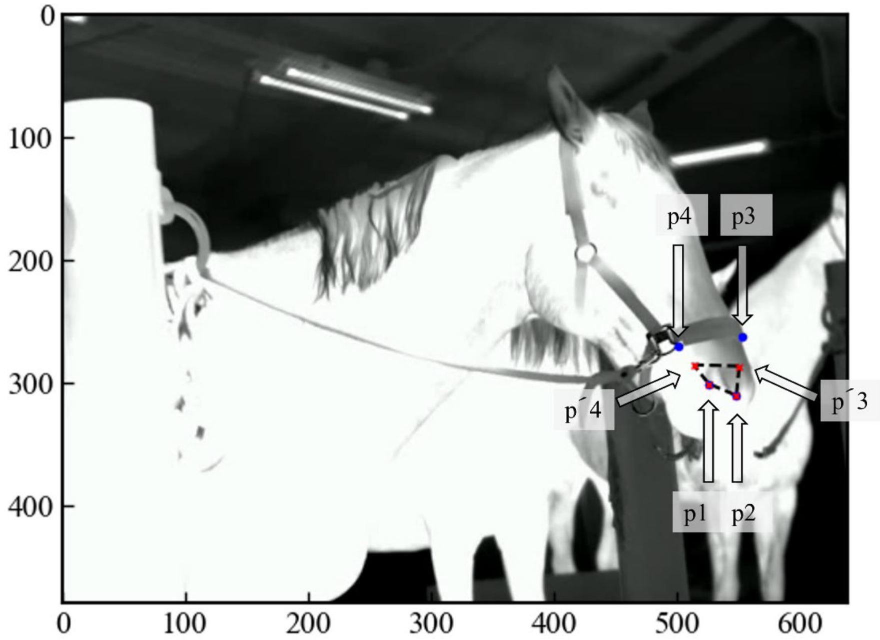

Fig. 2. An example of a 2D thermography image. The vertical and horizontal axes are both in pixels. The area enclosed by the dotted line is the target of the analysis.

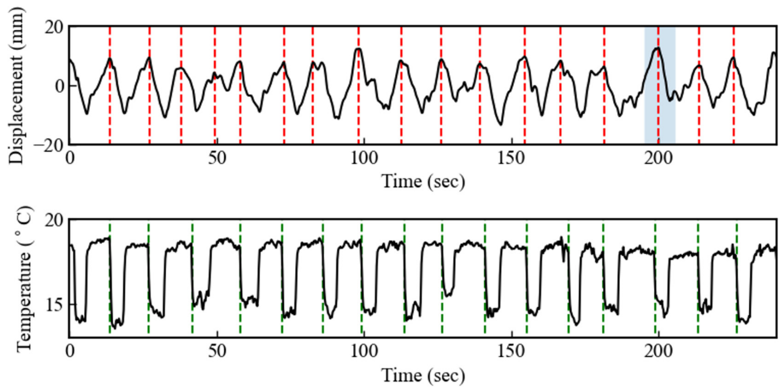

Fig. 3. The displacement measured by radar (upper panel) and the temperature measured by thermal imaging (lower panel) of a stable horse. The dotted line shows the respiratory timing. Blue areas in the upper figure show an unreliable frame area that includes high-speed movement in the first experiment.

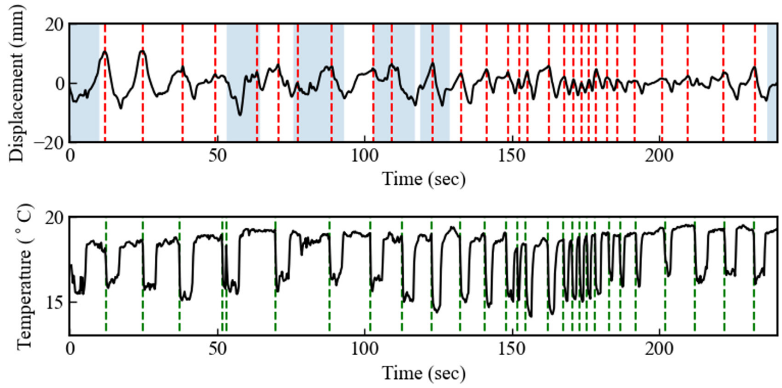

Fig. 4. The displacement measured by radar (upper panel) and the temperature measured by thermal imaging (lower panel) of an unstable horse. The dotted line shows the respiratory timing. Blue areas in the upper figure show an unreliable frame area that includes high-speed movement in the second experiment.

Therefore, from the viewpoint of animal welfare, it is important to measure changes in the respiratory systems of horses in a simple, non-contact manner. In this case, a radar response may detect disturbances in the resting state at night.

Body sway, rather than differences in respiratory rate, may be responsible for the error between the respiratory timing measured using the thermal imaging camera and that obtained from the radar. The radar captures displacement in the direction of the line of sight. Therefore, body sways other than breathing will be captured because these are bigger movements than those caused by breathing. The point at which the radar detects a subtle shift in body surface motion and the point at which the thermal imaging camera measures a drop in the temperature of cold air entering the nose are two different points of respiration. Therefore, a discrepancy between the timings of the detected breaths can be expected (2.5 and 0.93 sec as the root mean square error in the first and second experiments, respectively).

The radar system used in this study was optimized for humans, and the system was not modified for horses. Nevertheless, this study showed that it is still possible to measure the respiratory rate in a horse using this system with high accuracy even if the horse is standing, where the magnitude of swaying is likely to significantly impact radar measurements. The radar technology used in this study can localize individuals and therefore does not require additional complex processing, such as thermal imaging analysis. Thermal imaging cameras that are capable of two-dimensional measurements and are accurate enough to capture the presence or absence of breathing are expensive. With the mass production of radar modules in recent years, it has become possible to obtain radar modules at a relatively low cost. Another issue is the possibility of not being able to detect breathing well when the temperature of the exhalation is similar to the ambient temperature. Radar technology is valuable in that it can be used for measurements regardless of the environment. It is highly likely that radar is also capable of measuring in the rain, and this will be verified in the future. The 79-GHz band used by this radar technology is widely used in several countries, and this technology can be applied to radars that can be used in many countries.

This short report demonstrates the feasibility of measuring the respiratory rate in large animals using an optimized radar system for humans. Quantitative data collection and system modification should be considered in future studies. Moreover, this system should be validated for multiple horses of the same species as well as for multiple species of horses.

Several large mammals, such as horses, elephants, and giraffes, sleep in a standing position [14]. The present study is the first to report the measurement of the respiration rate of a large animal in a quadruped standing position remotely by radar technology. By modifying the module, the system can be applied to a wide range of animals with body surface amplitude changes caused by respiration. Since radar detects body surface movements associated with breathing, it can be applied regardless of whether breathing is through the nose or mouth.

Using radar technology with humans, it is possible to measure the respiratory rates of multiple individuals using a single radar module [2]. Future prospects include the application to animal species other than horses, the measurement of the respiratory rates of multiple horses in a stable, and the measurement of heart rates in addition to respiratory rates.

CONFLICT OF INTEREST. The authors declare no conflict of interest.

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REFERENCES

1. Hu M, Zhai G, Li D, Fan Y, Duan H, Zhu W, Yang X. 2018. Combination of near-infrared and thermal imaging techniques for the remote and simultaneous measurements of breathing and heart rates under sleep situation. *PLoS One* **13**: e0190466. [Medline] [CrossRef]
2. Koda T, Sakamoto T, Okumura S, Taki H. 2021. Noncontact respiratory measurement for multiple people at arbitrary locations using array radar and respiratory-space clustering. *IEEE Access* **9**: 106895–106906. [CrossRef]
3. Kranjec J, Beguš S, Geršak G, Drnovšek J. 2014. Non-contact heart rate and heart rate variability measurements: a review. *Biomed Signal Process Control* **13**: 102–112. [CrossRef]
4. Kumar B, Manuja A, Gulati BR, Virmani N, Tripathi BN. 2018. Zoonotic viral diseases of equines and their impact on human and animal health. *Open Virol J* **12**: 80–98. [Medline] [CrossRef]
5. Mathis A, Mamidanna P, Cury KM, Abe T, Murthy VN, Mathis MW, Bethge M. 2018. DeepLabCut: markerless pose estimation of user-defined body parts with deep learning. *Nat Neurosci* **21**: 1281–1289. [Medline] [CrossRef]
6. Mellor DJ, Beausoleil NJ. 2017. Equine welfare during exercise: an evaluation of breathing, breathlessness and bridles. *Animals (Basel)* **7**: 41. [Medline] [CrossRef]
7. Nath T, Mathis A, Chen AC, Patel A, Bethge M, Mathis MW. 2019. Using DeepLabCut for 3D markerless pose estimation across species and behaviors. *Nat Protoc* **14**: 2152–2176. [Medline] [CrossRef]
8. Portier K, Ida KK. 2020. K. Editorial: anesthetic risk and complications in veterinary medicine. *Front Vet Sci* **7**: 397. [Medline] [CrossRef]
9. Sakamoto T, Imasaka R, Taki H, Sato T, Yoshioka M, Inoue K, Fukuda T, Sakai H. 2016. Feature-based correlation and topological similarity for interbeat interval estimation using ultrawideband radar. *IEEE Trans Biomed Eng* **63**: 747–757. [Medline]
10. Santarpia JL, Rivera DN, Herrera VL, Morwitzer MJ, Creager HM, Santarpia GW, Crown KK, Brett-Major DM, Schnaubelt ER, Broadhurst MJ, Lawler JV. 2020. Aerosol and surface transmission potential of SARS-CoV-2. *Sci Rep* **10**: 12732. [Medline] [CrossRef]
11. Strutzke S, Fiske D, Hoffmann G, Ammon C, Heuwieser W, Amon T. 2019. Technical note: development of a noninvasive respiration rate sensor for cattle. *J Dairy Sci* **102**: 690–695. [Medline] [CrossRef]

12. Villarroel M, Jorge J, Meredith D, Sutherland S, Pugh C, Tarassenko L. 2020. Non-contact vital-sign monitoring of patients undergoing haemodialysis treatment. *Sci Rep* **10**: 18529. [Medline] [CrossRef]
13. Wang P, Ma Y, Liang F, Zhang Y, Yu X, Li Z, An Q, Lv H, Wang J. 2020. Non-contact vital signs monitoring of dog and cat using a UWB radar. *Animals (Basel)* **10**: 205. [Medline] [CrossRef]
14. Zepelin H, Siegel JM, Tobler I. 2005. Mammalian sleep. *Princ Pract Sleep Med* 91–100.