Suitability of a passive infrared sensor system for detecting individual calf activity

J. Ahmann[1,*], M. Trilling[2], A. Baumeister[2], A. Pelzer[2] and W. Büscher[1]
[1]*Institute of Agricultural Engineering, University of Bonn, Germany*
[2]*Chamber of Agriculture North-Rhine Westphalia, Agricultural Centre Haus Düsse, Germany*
[*]Corresponding author: Johanna Ahmann, johanna.ahmann@uni-bonn.de

Abstract

Calves' health and welfare are critical on any dairy farm because they are the basis for remounting. Therefore, monitoring calf health to raise well-developed calves is crucial to successful calf management. Due to advancing digitalization, automatic monitoring systems allow for conclusions about possible animal diseases based on various parameters, like activity. Thus, these systems are widely used in livestock farming. Progress can also be observed in calf husbandry, even if the number of systems is still small. This study aims to validate the suitability of a passive infrared sensor system used in individual calf housing to detect the activity levels of calves. The passive infrared detector (PID) was attached to three separate pens to assess the accuracy under practical conditions. We installed a camera system as a reference method for activity monitoring to record the three pens during the six-month observation period. A trained person evaluated the video footage, extracting the calves' behavior using an ethogram. The video-based behavior assessment was compared to the sensor-detected activity levels for three focus calves (72 hours per calf). The results showed that the PID could detect general changes in activity. In addition, the circadian rhythm of the calves could be reproduced. A deviation in activity levels occurred when a calf was lying down, which may have been caused by the calf's coat.

Keywords: calf husbandry, animal welfare, livestock management

Introduction

Raising vital and healthy calves is essential on dairy farms. Not only do the calves serve to remount the herd, but diseases can lead to increased treatments, losses, and economic costs (Hultgren and Svensson 2009; Zitzmann et al., 2019). In addition, consumer attitudes have changed considerably in recent years, and there is a growing demand for systems adapted to the unique needs of the species or individual animals. Consequently, the welfare and health of calves have become increasingly important (Halachmi et al., 2019). The recording and comparison of animal behavior is a critical component of assessing animal welfare and health in livestock farming (Dawkins 2003). Farmers have long used animal behavioral changes as indicators of disease detection (Weary et al., 2009). Usually, farmers record the behavior and activity of animals visually during feeding. However, owing to increasing herd sizes (Knight 2020), individual animal control is a very time-consuming and labor-intensive procedure, and individual animal observation is still challenging to implement in dairy farming (Breer and Büscher 2006). Video recording animals and evaluating their behavior, primarily used as a scientific standard, is also very labor-intensive, and the results can depend on the person performing the task (Weary et al., 2009). Therefore, it is essential to develop systems that can detect diseased calves early, objectively, accurately, and easily from a practical perspective. Advancing digitalization and the associated development steps in sensor technology have led to an ever-increasing number of available assistance systems on the market, bringing new and further developed approaches to dairy farming (Sun et al., 2021). This development has also led to various sensor technologies in calf husbandry, which can record animal-specific parameters and behavioral aspects, including feed intake, activity, and body temperature (Dawkins, 2003). Sensor systems have some advantages; however, the number of techniques available for calf husbandry is still limited.

Sensor technologies promise optimization for both animals and farmers. Real-time data on the activity and performance of calves allow conclusions about deviations from normal behavior and health status. The additional information can support a well-run management system and provide a comprehensive picture of the health status of calves (Halachmi et al., 2019). Passive infrared detectors (PID) are a non-invasive sensor technology that has gained increasing attention in various animal husbandry systems. Any body with a temperature greater than zero emits infrared radiation directly related to body temperature. The PID takes advantage of this principle by measuring body movements within a specific area based on changes in varying radiation from different surfaces, e.g., resulting from the movement of warm bodies (Besteiro et al., 2018b). Thus, the PID output depends on the temperature difference between the moving body, ground, and the moving body speed (Pedersen and Pedersen 1995). The usability of these sensors has been tested in various studies using different animal species and study designs (Puppe et al., 1999; Wachenfelt et al., 2001; Jasmund et al., 2020). However, to the authors' knowledge, no studies have examined PIDs' utility in recording individual housing calves. As a result, the purpose of this research was to validate the suitability of a PID for measuring calves' activity in single pens.

Materials and methods

Animals and housing

The study was conducted at the Agricultural Center Haus Düsse in North Rhine-Westphalia, and the experimental period covered six months, from May 6th, 2022, to October 20th, 2022. A mobile calf hutch with three separate pens was used in this study. The hutch had external dimensions of 320 cm W × 250 cm L (without the roof overhang), and a single pen measured 100 cm W × 162 cm L × 100 cm H. The pen had a total dimension of 335 cm W × 300 cm L, with a height of 230 cm at the highest point of the roof overhang. Immediately after birth, the calves were moved to an individual pen littered with straw and fed four liters of colostrum. Further feeding was provided *ad libitum*, with the bucket filled with acidified whole milk in the morning (07:00 am – 08:00 am) and evening (04:00 pm – 05:30 pm). After three weeks, the calves were moved to the group housing, and the barn was cleaned for new occupancy.

Passive infrared detector and visual assessment as reference method

Activity data were collected every minute using PIDs (part no. 1362922, renkforce, Conrad Electronic SE, Hirschau, Germany), which typically created an analog signal. Due to certain technical modifications, the signal for this specific PID is not displayed in volts but is directly converted into a percentage value. The resting state of a PID corresponds to 1 V or an activity level of 0%, and an activity level of 100% equates to 10 V. The PID also features a signal light, which allows easy and quick testing of performance and functionality. We installed one PID per separate pen at a height of 100 cm, with the lens at a height of 76 cm above the litter. For more precise alignment, the PID lenses were covered with a plastic sheath (Figure 1). A data logger (ALMEMO 710®, Ahlborn Mess- und Regelungstechnik GmbH, Holzkirchen, Germany) recorded the measurement data every minute. Extracted data from the logger were entered and managed in Excel 2019 (Microsoft Corp., Redmond, WA). During the experimental period, employees dismounted the PIDs to clean the barn and returned them to the same pen.

Simultaneously, a video camera (Berghoch, Hartford Electronics GmbH, Dortmund, Germany) recorded the calves during the entire rearing period to visually assess activity data. We placed the camera at the height of 202 cm in the middle of the barn so that the camera covered all three separate pens. Visual estimation was used as a reference method. We randomly selected three focus calves within the experimental period and analyzed the video data for each calf for 72 hours. A trained employee classified the calf's behavior per minute into six categories based on the ethogram presented in Table 1. The behavior that lasted the longest within the minute of consideration was recorded. Calf 1's video data was analyzed from May 9th to May 12th, 2022; calf 2's data was analyzed from August 30th to September 2nd, 2022; and calf 3's data was analyzed from September 30th to October 3rd, 2022. We divided the 24 hours into two intervals based on feeding times to evaluate PID and video data. The first interval (daytime) began before the first feeding at 7:00 am and continued until the second feeding at 4:00 pm. Accordingly, the second interval (nighttime) began at 4:01 pm and continued until 6:59 am.

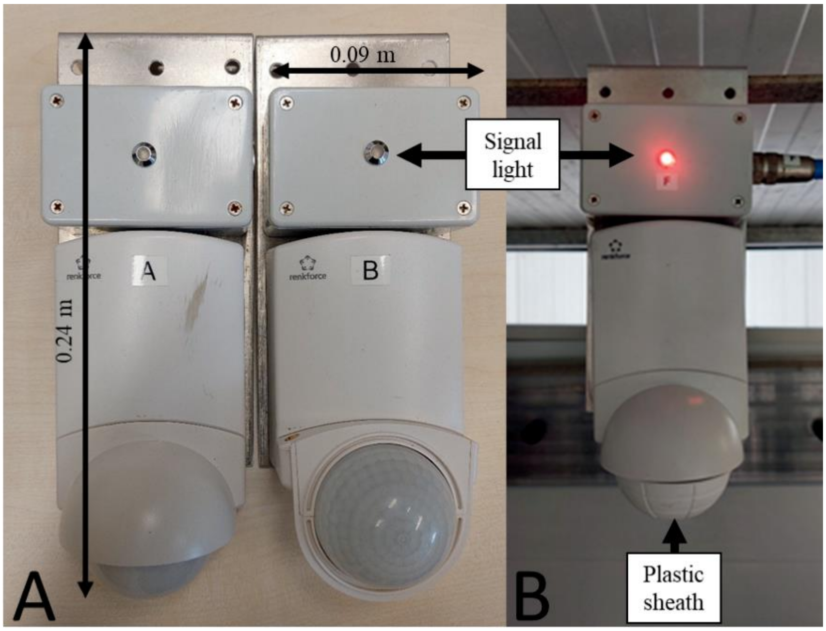

Figure 1: Image of the passive infrared detector with uncovered (A) and covered lens (B) and signal light for functional testing

Table 1: Ethogram for visual validation of the behavior of the three focus calves

Behavior	Category	Definition
Lying without movement	I	The calf lies flat on its side with its head resting on the litter, or the calf lies on its sternum with its neck curled and its head resting on its body (with no jaw movements).
Lying with movement	II	The calf lies in a supine or sternal position, with some head movement but no rumination.
Standing without moving	III	The calf is in an upright position. Uniform, motionless loading of all four limbs. The head and tail are not moving.
Standing with moving	IV	The calf is in an upright position. All four limbs are loaded evenly. There is no movement forward (running), to the side, or backward. The legs remain on the floor of the stall and do not lift off of it. Movements are made with the head or tail.
Walking	V	The calf is in an upright position. All four limbs are loaded evenly. There is no movement forward, to the side, or backward. The legs remain on the floor of the stall and do not lift off of it. Movements are made with the head or tail.
Running, jumping, and playing	VI	The calf bucks and lunges backward. It either moves very fast in one of the directions or jumps off the barn floor. Play behavior is also included (with straw, etc.).

Results

Within six months, 18 calves occupied the three individual pens. The period between housing out the calves and using the boxes for new calves was between four and ten days. The PIDs could not record data in June and July because of a technical problem. Consequently, we excluded six calves from the evaluation period. Finally, the assessment included activity data of 12 calves. During observation, the three PIDs recorded activity values ranging from slightly above 0% to nearly 100% for all 12 calves. Compared with the visual observations, the PIDs could determine strongly varying values for the three focus animals for strong and less dynamic behaviors (Table 2). Because of the varying outdoor temperatures measured during the focus periods, the outdoor temperature is ruled out as an influencing factor in the PIDs' widely varying measured values.

Table 2: Minimum and maximum PID values for the three focus calves compared to visual observations, divided into dynamic and less dynamic behaviors and the temperature range during the observation period

	Temperature range		Dynamic behavior[1]		Less dynamic behavior[2]	
Focus Calf	Min (°C)	Max (°C)	Min (%)	Max (%)	Min (%)	Max (%)
Calf 1	4.9	25.8	1.0	99.2	0.3	100.0
Calf 2	9.7	25.7	1.3	85.9	0.9	99.8
Calf 3	2.6	17.5	0.8	97.7	0.5	99.6

[1]Category: IV, V, and VI; [2]Category I, II, and III

The PIDs demonstrated a circadian rhythm with lower mean activity levels at night and higher levels during the day for all 12 calves (Day: 15.9% ± 22.3, Night: 12.7% ± 20.2). The visual comparison could confirm this finding for the three focus calves. After feeding, the three calves were observed to have lower activity for a short period (30 min). After 45 to 75 min, an increase in activity was recorded, up to category VI. The PID values also represented these observations. In some cases, when the calf was directly under the corresponding PID, the PIDs recorded very high readings (≥80%) for category I and II.

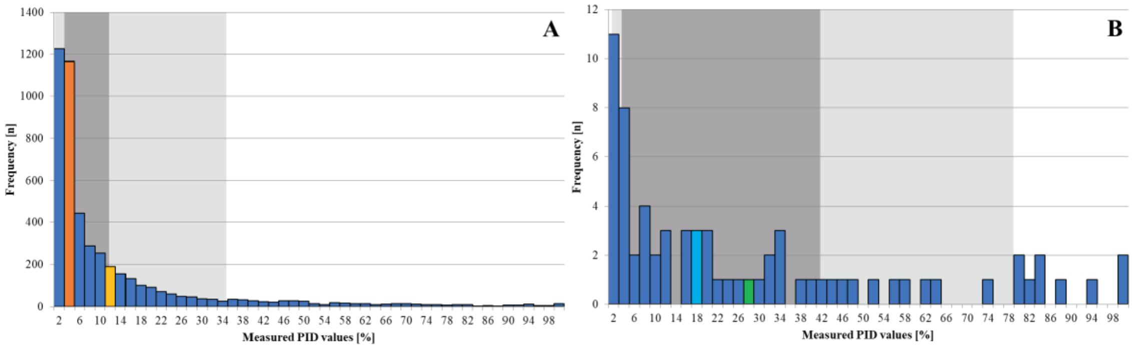

Figure 2: Frequency of PID values [%] for the three focus calves for the categories *I* (A) and *VI* (B) observed by the video recordings and categorized based on the ethogram (light gray area: 10.0% to 90.0% percentile; dark gray area: 25.0% to 75.0% quantile; (A) n=4,876; orange=median of 4.2%; yellow=mean of 12.0%; (B) n=70; blue=median of 17.8%; green=mean of 28.1%%)

Figure 2 shows the distribution of PID values recorded for the three focus calves in the categories *I* and *VI*. We observed a shift in the mean from 12.03% (*I*) to 28.06% (*VI*). For calf 1, values ≥80% were recorded for 74 min during the focus days. Visual research revealed that the calf behaved in category I and II for 53 of the 74 min. This is a 72% overestimation of activity based on the PID values compared to the visual observation. Similar observations were made for calf 2 and 3. The PID measured values ≥80% for calf 2 for 73 min. However, the calf exhibited category I and II behavior in 75% of the cases. For focus calf 3, values ≥80% were measured by the PIDs for 106 min, with category I and II demonstrated by visual observation for 82% of the time.

Discussion

Previous research has shown that the activities of pigs in groups can be mapped using PIDs (Ni et al., 2017; Besteiro et al., 2018a; Jasmund et al., 2020). PIDs are attractive for measuring animal activity because they are inexpensive (Ni et al., 2017), easy to handle, resistant to barn conditions, and simple to install. Since activity is also a relevant indicator for the early detection of health disorders in calves (Weary et al., 2009), the present study investigated the suitability of PIDs for measuring individual calf activity. In our study, the PIDs recorded a circadian rhythm with lower activity levels at nighttime than in the daytime. This finding accords with the normal behavior of calves since calves are diurnal animals and are more active during the day than at night (Veissier et al., 2017). Veissier et al. (2017) established that disturbances in the physiological or pathological state of the cow influence this rhythm. This aspect could be included in the automatic recording of calf activity, with subsequent inference of health disorders. As found in the present study, varying activity levels depending on feeding management have already been detected by Ngwabie et al. (2011) in dairy cattle using PIDs.

In principle, different activity levels were recorded by the three attached PIDs; however, the measured values could not always be reconciled with the activity observed via video recording. The high values obtained when the calf lay directly beneath the PID are problematic. The PIDs determined the highest measured values to a large extent within the scope of this behavior. Since the calves showed inactivity or just little movements during this behavior, pure activity cannot explain the high values. In some previously conducted studies, PIDs were found to overestimate activity (Besteiro et al., 2018a; Jasmund et al., 2020). However, it must be noted that the data collection in these studies was performed with group-housed animals and not with single-housed animals. In addition, the previously conducted studies showed low values of overestimation. In the study of Besteiro et al. (2018a), the PIDs overestimated the activity by 2.59% compared to visual observations. However, the authors also detected discrepancies between the PID measurements and the visual observations when almost inactive behavior was recorded during the visual observation. The authors attributed this to the frequency rate for the visual observations, which was two minutes. This meant that successive low activity levels between two observations were not recorded. However, since the present study evaluated the behavior of the three focus calves per minute, the discrepancies here can be attributed less to the observation frequency. One reason for the high values in this study might be the calf's coat. Okada et al. (2013) showed that the hairiness of the object under consideration influences the results of infrared thermography measurements. The muzzle, eyes, and ears emit more heat than the rest of the calf because these areas are covered with less hair. These body parts were placed in the prone position directly underneath the PID. As a result, the high values might be attributed to the position of the head in relation to the measured areas rather than to calf activity. One study evaluated a data logger on the calf, which accurately recorded lying time. In the trials, differences were found in the attachment of the sensor to the front and hind legs (Bonk et al., 2013).

Previous research showed that sensor positioning influences measurement performance and accuracy (Besteiro et al., 2018a). This study aimed to record the activity of a single calf; while excluding all other influences, such as calves in other pens or employees in the immediate environment of the barn. The plastic cover supported this approach and allowed a more specific lens alignment. However, the plastic cover and the height restriction imposed by the barn ceiling resulted in dead zones where no activity could be recorded. Therefore, the PID positioning should be evaluated, adjusted, and verified in barns of other dimensions. The transverse movements of the calf are easily captured when the PID is mounted centrally above the pen because the PID detects these movements better due to their orientation (Besteiro et al., 2018a). Vertical directions (e.g., bucking and jumping) are recorded to a lesser extent. Mounting the PID at a different angle or frontally would eventually capture the vertical movements better. Jensen et al. (1998) found that calves in smaller barns show less play behavior and that movements that involve lifting the rear extremities are performed to a lesser extent. Increased space may result in a more accurate recording of activity levels by the PIDs due to better opportunities for the calf to act out natural behaviors. It would be interesting to investigate the usability of PIDs in the context of group housing for calves. For this purpose, several PIDs shall be mounted in different positions and angles above a group pen.

Conclusions

The usability of PIDs has already been investigated in some studies with different animal species, and promising results have been found. This paper examines the usability of PIDs for measuring activity in calves kept in single pens. We have shown that the PIDs used in the study show some potential to capture different activity levels in single-housed calves. Under the conditions of this study, the PID appears to overestimate the activity level for 'lying down without movement' and 'lying down with movement'. However, certain tendencies of activity levels, for example, depending on the time of day or feeding times, could be demonstrated. It should be noted for future research that body hair appears to influence measurements, as does the placement of the PID above the calf. PIDs have only been tested on a limited number of dairy cattle or calves, so more research is needed to define their usability for calf husbandry. The current study provides some starting points and factors for further research.

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