ACTA IMEKO
ISSN: 2221-870X
March 2024, Volume 13, Number 1, 1 - 4

Assessing accelerometer thresholds for cow behaviour detection in free stall barns: a statistical analysis

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ABSTRACT
Monitoring daily cow behavioural activities of cows in livestock farms is strategic for improving the herd management. For this reason, IoT techniques and smart sensors are become the most common technological support in barns.
The aim of this paper is to validate the use of predefined accelerometer thresholds in timely detecting of cow behavioural activities through the statistical analysis of the data acquired from accelerometers housed in collars. Applying ANOVA and TUKEY tests to the median of the accelerations measured with 4 Hz sampling, the behavioural activities analysed in this study, i.e., feeding, lying, rumination, were found to be discriminable along one or more axes. This could allow the implementation of threshold-based algorithms in the firmware of devices housed in the cow collars.

Section: RESEARCH PAPER

Keywords: free stall barn; cow behaviour; IoT

Citation: S. M. C. Porto, M. Bonfanti, D. Mancuso, G. Cascone, Assessing accelerometer thresholds for cow behaviour detection in free stall barns: a statistical analysis, Acta IMEKO, vol. 13 (2024) no. 1, pp. 1-4. DOI: 10.21014/acta_imeko.v13i1.1682

Section Editor: Leopoldo Angrisani, Università degli Studi di Napoli Federico II, Naples, Italy

Received September 26, 2023; **In final form** February 26, 2024; **Published** March 2024

Funding: PRIN 2017 project "Smart dairy farming: innovative solutions to improve herd productivity" (ID: E64I18002270001) and P.O. FESR SICILIA 234 2014/2020 - "Innovazioni tecnologiche negli allevamenti per bovine da latte: sviluppo del prototipo di un sistema automatico di monitoraggio del comportamento delle bovine per il miglioramento del benessere e delle prestazioni produttive e riproduttive (CowTech)" (ID: G69J18001020007) both coordinated by Prof. Simona M.C for the University of Catania.
Agritech National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them

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1. INTRODUCTION

In recent years, technological support in farms has become increasingly important. As known from numerous studies, animal behaviour is a clear indicator of both physiological and physical state: feeding, lying and rumination are the main daily activities of ruminant livestock [1]. Monitoring these activities proves to be crucial for understanding the health state of the animal and, therefore, allows for preventive action. This task is also very useful for improving the farm management and then guaranteeing increases in production. Control techniques based on human observation suffers of several limitations: in addition to being time-consuming, they can prove ineffective when the ratio between the number of operators and animals is low. The introduction of IoT techniques and wearable sensors have allowed development of different systems for monitoring animals inside and outside the barn [2]. Smart sensors allow the collection of a big volume of data, which can subsequently be processed, and provide important information about the conditions of the animals. Data processing makes it possible, under specific conditions, to alert the farmer about health problems in animals. At the present state of the art, many multi-purpose systems have been proposed to simultaneously perform various tasks such as: behaviour detection [3], animal identification [4], welfare and health monitoring [5]. Vazquez et al. (2015) [6] have developed a decision-tree algorithm that allows classifying lying, standing, and feeding in cows, starting from accelerometers data. Arcidiacono et. al [7] have proposed an inertial sensor-based system to perform real-time cow step counting in free-stall barns. Shen et al. (2020) [8] have proposed an automatic sensor-based system for the recognition of ingestive behaviour in cows. Benaissa et al. (2019) [9] have proposed an automatic behaviour classification system for cows in barn and investigated the different locations where the accelerometers should be mounted on cows to better classify the various behavioural activity; they have found the best sensors arrangement for feeding detection to be on cow collar, while that for lying detection on the cow leg. The development of animal monitoring systems is a complicated task as depending on different factors: ability of the devices to work under unfavourable conditions (i.e., the presence of dust and shocks), battery life, grid electricity availability and presence of a constant internet connection.

The main objective of this paper is to analyse accelerometers data acquired in barn to prove the utility of pre-fixed accelerometer thresholds in automatic detection of cow behavioural activities. Algorithms based on predefined thresholds lend themselves well to this type of application as they can be easily implemented in devices and allow real-time detections, showing to be not expensive in terms of computational activity. Furthermore, the computation directly on the device involves a reduction in energy consumption, limiting the use of the telecommunications network, which is often lacking in rural areas.

2. MATERIAL AND METHODS

2.1. Experimental site

The experimental trial was carried out in a free-stall barn located in Vittoria (RG), Sicily, at 234 m a.s.l (Figure 1). The building has a rectangular plan with dimensions of 55.60 m × 20.75 m; the longitudinal axis is oriented in a north-east - south-west direction. The sides facing south-east, north-east and north-west are open, while the remaining one (facing south-west) is completely closed. As shown in Figure 2, the rest area consists of 64 stalls, 1.20 m × 2.15 m in size, with a decubitus surface made with quarry sand, arranged in two rows head-to-head and divided into three partitions by means of metal fences. The stalls are bounded by the service lane and the feed lane. These two rows of stalls are connected by six transversal corridors which separate the three resting areas. Inside the barn, an area (Pen 1) having a length of 15.40 m (in the direction parallel to the longitudinal axis of the stable) and a width of 11.50 m was specifically identified for carrying out the experiment object of the present study. This partition included a resting area consisting of 16 cow stalls with the related service and feeding lanes connected by two transversal corridors. Fifteen lactating Holstein-Friesian cows were housed in the area described above.

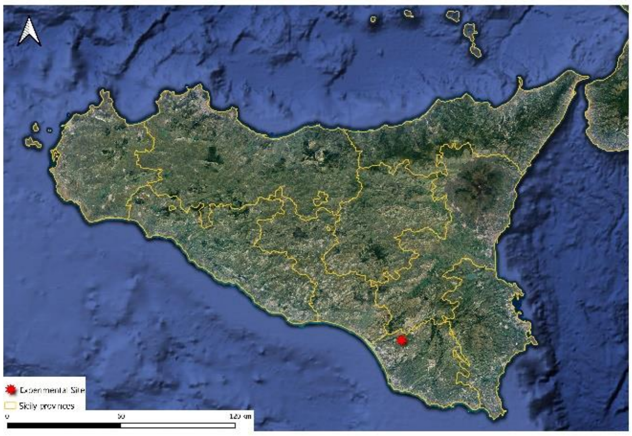

Figure 1. Location of the barn where trial was carried out.

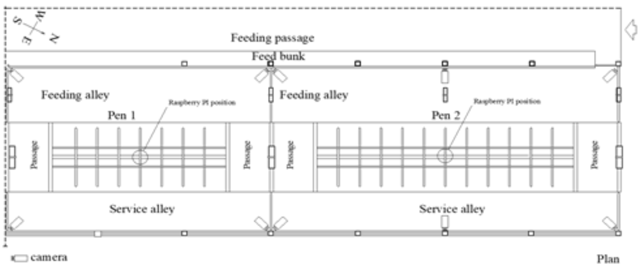

Figure 2. Plan of the barn.

2.2. Herd Management

In a typical barn, the farmer applies daily herd management techniques which has an influence on the behavior of the cows. The farmer implements a constant routine of daily operations, which can differ, however, between the summer and winter periods.

For the present study, from the entire herd, two Holstein-Friesian cows were selected by the breeder and one collar for the detection of behaviours was mounted on each of them. The experiment tests were performed in April 2022, for a time interval of 5 days. During this period, the farmer performed the first milking from 6:20 to 7:00 a.m. and the second milking from 4:20 to 5:00 p.m. Data from these time intervals were not considered because they regarded the milking phase which is not object of the present analysis. From 8:00 to 9:00 a.m. the farmer carried out the cleaning of the feeding alley and the distribution of clean sand in the stalls. Even this period was not taken into account, since the cows were confined by the farmer within a single box.

2.3. Data Collection system

To collect data the system proposed by Porto et al. (2022) was used [10]: it consists of an electronic device, attached to the cow body (Figure 3), and a WebApp specifically developed to provide the data visualization. The electronic device is equipped with a triaxial accelerometer, a 32-bit microcontroller, a GSM/GPRS quad band module, a LiSOCL2 high-capacity battery and a flash memory. Acceleration components along x, y, and z axes were acquired with a frequency of 4 Hz and sent to a cloud, once an hour. Then, they were processed and displayed through the

Figure 3. Collar equipped with the device during the cow feeding.

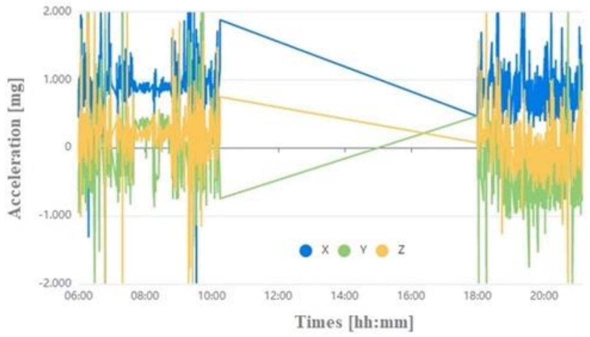

Figure 4. Data visualization and acquisition from the WebApp.

WebApp (Figure 4). The device employed in this study is an experimental prototype operating on the GSM network. Due to the high energy consuming, especially during data transmission, the duration of the experimental tests could not be extended any further, but data acquired were enough for achieving acceleration thresholds related to the behavioural activities analysed in this paper.

Table 1. Behavioural activities class.

Behaviour	Samples	%
F	7788	25.56
L	18655	61.22
LR	3765	12.30
R	265	0.87
Total	30473	100

Table 2. ANOVA test on x-axis accelerations.

Median label	*N*	*Mean Value*	*StDev*	95 % CI
F	7788	911.20	111.14	(907,30; 915,10)
L	18655	936.35	58.60	(933,825; 938,865)
LR	3765	950.33	33.97	(944,718; 955,937)
R	265	966.81	43.86	(945,66; 987,95)

Table 3. ANOVA test on y-axis accelerations.

Median label	*N*	*Mean Value*	*StDev*	95 % CI
F	7788	226.96	265.44	(222,31; 231,62)
L	18655	-172.72	173.38	(-176,73; -170,72)
LR	3765	-174.70	112.04	(-181,39; -168,00)
R	265	-12.43	148.74	(-37,66; 12,81)

Table 4. ANOVA test on z-axis accelerations.

Median label	*N*	*Mean Value*	*StDev*	95 % CI
F	7788	38.35	171.65	(33,31; 43,38)
L	18655	192.32	136.06	(189,068; 195,570)
LR	3765	230.91	69.99	(223,67; 238,14)
R	265	157.46	94.60	(130,18; 184,73)

Table 5. TUKEY test results.

Median label	Grouping X	Grouping Y	Grouping Z
F	A	A	A
L	B	B	B
LR	C	B	C
R	C	C	B

2.4. Dataset

In this study, the dataset was composed by the following behavioural activities: feeding at the manger (F), rumination in standing position (R), lying (L), and rumination in lying position (LR). The walking activity was excluded from the analysis because it was monitored by pedometers for oestrus detection [11]. The data acquired from accelerometers were labelled by using video acquisitions from surveillance cameras placed in the barn (Figure 2). Minor behavioural activities were detected during the visual inspection of the video recordings and the subsequent labelling process. To limit the presence of any outliers in the data set, it was decided to eliminate the samples related to the minor behavioural activities.

2.5. Data analysis

Descriptive statistics were used to analyse the main metrological parameters (mean value, peak, minimum value, and standard deviation) of the acceleration data acquired along x, y, and z axes, grouped by behavioural activity. Then, ANOVA test was adopted to compare the data concerning the behavioural groups under examination, to detect statistically significant

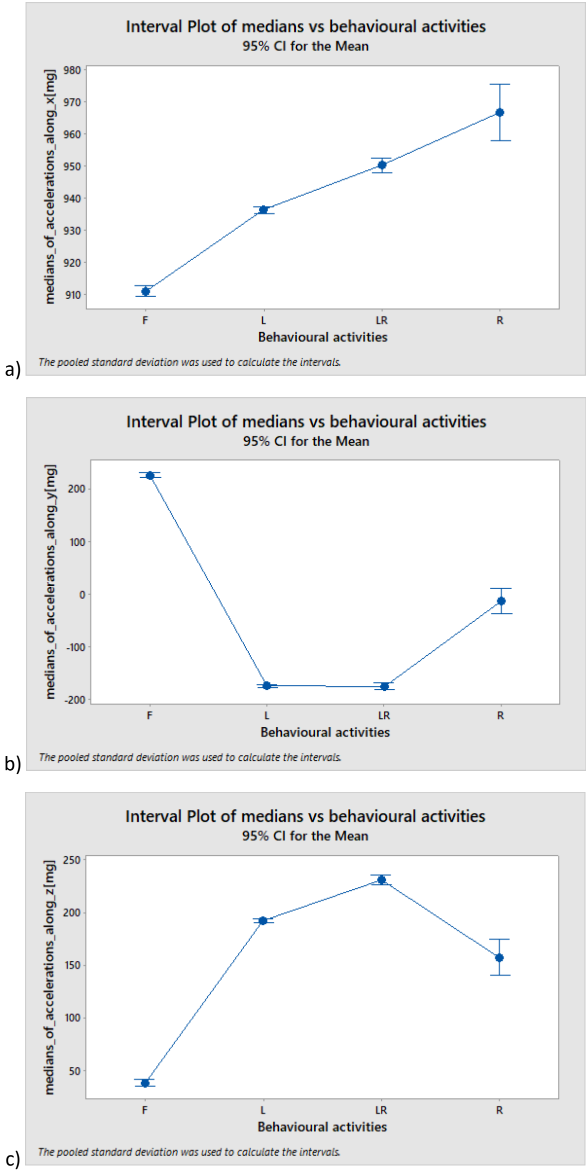

Figure 5. TUKEY test plots along: a) x-axis, b) y-axis, c) z-axis.

Table 6. Discriminable values.

Behaviour	Acceleration component		
	x	*y*	*z*
F	Required	Required	Required
L	Required	Not required	Not required
LR	Not required	Not required	Required
R	Not required	Uncertain	Not required

differences, and to define the working range for acceleration along each axis. The ANOVA test was carried out by computing the median of the accelerations measured in one second (4 Hz sampling) for each behaviour (see Table 1 to Table 4). Finally, the Tukey test was applied both to compare the behavioural activities and to identify any overlaps and axes suitable for discriminating behaviour (Table 5 and Figure 5).

3. RESULTS AND DISCUSSION

The analysis performed allowed for the determination of the acceleration components needed to set thresholds for distinguishing cow behavioural activities. Table 2, Table 3 and Table 4 show the results from the ANOVA test applied to accelerations along the x, y, and z axes for each behavioural group of the cows. In each table are reported: the number of samples associated with the behaviour for the specific axis (N), the mean value (Mean), the standard deviation (StDev) and the 95 % confidence interval of the total samples (CI). The confidence interval was helpful to identify the accelerometric thresholds associated with each behaviour. Figure 5 and Table 5 show the three graphs and the results from Tukey's test on the ANOVA test. The tables show the number of samples associated with the behaviour for the specific axis (N), the mean value (Mean), and the group (Grouping) in which different letters are reported. If several behaviours share the same letter, such behaviours must be considered non-discriminable. The results showed that feeding at the manger (F) behaviour is discriminable on all three axes. The graph shows that the confidence intervals relating to this behavioural class are clearly distinguishable with respect to the other behavioural classes. Rumination in lying (LR) can be discriminated in the z-axis, since the graph shows values relating to the behavioural class in a well differentiated point with respect to the other classes behavioural. Along the x-axis the LR behaviour overlaps with class R, while along the y-axis it overlaps with class L. Rumination (R) can be discriminated only along y-axis. The result achieved for this class is uncertain since the number of samples available is very small and, therefore, the class R is strongly unbalanced when compared to the other classes. Lying (L) can be discriminated along x-axis. Along y-axis L overlaps with LR class and along z-axis it overlaps with rumination.

In summary, the discriminable values are found to be the following: the feeding at the manger (F) along all the three axes; rumination in lying position (LR) along the z-axis and lying along the x-axis (Table 6).

4. CONCLUSIONS

The present study allowed understanding which behavioural classes can be considered as distinguishable and on which axes. Feeding is the behaviour that was found to be distinguishable on all three axes. Future studies will have as objective the refinement of the threshold values, by using a larger sample of animals, and the use of the thresholds directly computed in the firmware of a device for the detection of cow behavioural activities in the barn.

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