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EXECUTIVE SUMMARY

Background	*At SmartCow RIs a large amount of data are recorded using new smart technologies on a routine basis or for experimental purposes. However, there is a lack of a common approach for validation of such devices.*
Objectives	*The objective of Task 7.1 is to develop and test uniform guidelines for validation of outputs from sensors for the recording of animal behaviour to be used within the SmartCow infrastructure.*
Methods	Protocols for validation of automatic recording of eating behaviour is developed based on report D7.1 *Guidelines for validation of sensor output* recorded at AU, INRA and IRTA. The protocols have been sent to all partners in WP7 for comments. Data were then collected following the protocols, and data were sent to AU for analysis and preparation of a draft of the report. Types of analysis, results and interpretations have been discussed via emails between INRA, IRTA and AU. Furthermore, INRA prepared a protocol for validation of output from a positioning system. This protocol and the output from the validation have also been the subject for discussion among the three partners.
Results & implications	The results of the validation show that both visits to the feeders and duration of eating are measured with high accuracy and precision. However, occasionally, cows perform other behaviours than eating when they are at the feeders. Thus, duration of eating is not as accurate, and the duration of not eating while at the feeders varied between facilities. The positioning system (CowView) detects positions with an accuracy of 15 cm in the INRA facility; nevertheless, the links between the position and the activity of the animal need to be thoroughly checked. All partners experienced that the guidelines were helpful in preparation of a protocol. However, we also identified that more information about statistics would be useful. The guidelines should specify that it is essential to check that the sensors and the video analysis are synchronised; if a systematic delay is observed between the two sets of data, then it must be corrected in the dataset. The video is generally the gold standard, but one must be aware that the observer can also make mistakes, so when a discrepancy between the data from sensors and the video is detected, one should check the video.

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SmartCow
an integrated infrastructure for increased research capability and innovation in the European cattle sector

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This report is based on work done in WP7 in SmartCow.

The first chapter concerns validation of output from automatic feeder systems at AU (Denmark), INRA (France) and IRTA (Spain) to measure duration of eating. The second chapter involves validation of a new system for recording of position and activity of cows, in place at one of the facilities. Lastly, we have included a short chapter with reflections on the use of the guideline for validation of sensor output as described in *D7.1 Guidelines for validation of sensor.*

1 A validation study of eating duration assessment from automatic feeder systems

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1.1 Introduction

In the SmartCow project (WP 7), a report has been produced to consult when planning a study to validate sensors for measuring cattle behaviour (SmartCow, 2019). The report was created as a checklist, easy to adopt to the type of study planned, as there are many new sensors for automatic measuring of cattle behaviour being developed, and new devices using different technologies frequently being introduced to the market.

Feeding time and feed intake are important aspects to consider when studying welfare, productivity and efficiency of dairy cows, and, over the last decade, a number of new methods for automatic recording of feeding behaviour have been developed. The feed visit time, as estimated by the Insentec system, has in previous validation shown to be highly correlated with manual observations ($R^2 \geq 0.99$; Chapinal et al., 2007), but, to the best of our knowledge, there are no published validation studies for the BioControl CRFI system or the MooFeeder system. The duration of a feeding visit includes behaviours related to eating, but there might also be periods when the cows are not actively engaged in eating while standing at the feeder. Therefore, visit duration does not necessarily correlate completely with eating duration. A recent study correlated chewing time recorded by MSR-ART noseband pressure sensors at the feeder with the total duration of a feeding visit for cows with access to Insentec feed bins (Pahl et al., 2016), but there is no available information of similar studies for the BioControl CRFI system or the MooFeeder system.

The purpose of this study was to test the guidelines for validation of sensor technology, developed in the SmartCow project, and to compare the outcome with tests conducted at different Research Institutes. As one of the most common and basic behaviour recordings within the SmartCow consortium is feeding time, we chose to test the guidelines by planning and conducting a validation study where the automatic recordings for when a cow enters and exits a feed bin were compared with manual observations of the same. In addition to this, we also tested how well the feeding time as recorded in the feed systems corresponds to manual observations of actual eating duration.

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1.2 Materials and methods

1.2.2 Animals and housing

1.2.2.1 Location 1 (AU)

Two groups of Holstein cows, approximately 120 cows, were housed in a free-stall barn (1:1 cubicle:cow ratio) with slatted concrete floors and automatic milking systems (VMS, DeLaval, Tumba, Sweden) with one milking robot per group. In total, 91 cows were observed for the study. In addition to two heifers with 0 days in milk (DIM), there were 34 primiparous (DIM 139 ± 100) and 56 multiparous cows (DIM 148 ± 99). The cubicles were equipped with mattresses and covered with a mix of cut wheat straw and sawdust distributed several times a day. A cleaning robot cleaned the floors once per hour. The cows were fed a partial mixed ration from 28 Insentec feed bins per group (stocking level approximately 2.1:1 cows per bin) and given up to 3 kg of concentrate in the VMS. The partial mixed ration consisted of grass and maize silage and a mix of rapeseed expeller and soybean (Table 1). Feed was delivered four times a day at 06 h, 1030 h, 1430 h and 18 h, and the cows had ad libitum access expect for the short periods where the feed bins were being filled. They had ad libitum access to two water troughs (0.5 × 2 m) on two different locations per group. The barn was naturally ventilated with light hours between 05 h and 22 h, and the study was conducted in September 2019.

The cows moved into one group at calving and stayed there during the remaining time of lactation. The groups consisted of heifers being trained to the system and primiparous and multiparous cows in all stages of lactation. The individual feeding space was divided by a metal structure to prevent displacements (Figure 1). All of the cows were trained to use the Insentec feed bins before they entered the lactation.

1.2.2.2 Location 2 (INRA)

Twelve cows (six Holstein and six Montbéliarde) were recruited for the experiment: two primiparous and four multiparous per breed (267 DIM, 14.1 kg milk/d; Table 1A, appendix). The 12 cows had access to a pen of 244 m^2 in the free-stall barn with 27 cubicles equipped with rubber mattress and filled with straw flour. They were fed grass silage and hay, distributed in different bins (6 for each ingredient, stocking density 2:1 per ingredient), and concentrates in a Delaval (Delaval Tumba, Sweden) automatic feeder. Cows were milked twice daily (0630 h and 1530 h) in a Delaval herringbone 2 × 14 milking parlour, and feed (Table 1) was distributed every morning after milking. Bins were refilled if necessary before afternoon milking, as cows were fed ad libitum. All cows had been trained to the BioControl Controlling and Recording Feed Intake (CRFI) system before the experiment. The barn was naturally ventilated with no thermostat control. Light cycle was 12 h minimum, and, when natural light was less than 12 h per day, artificial lighting was used from 0600 h to 1800 h. The floor was cleaned at least four times daily. The study was conducted in June 2019.

1.2.2.3 Location 3 (IRTA)

Four pens of Holstein cows with 18 cows and 15 feed bins in each pen were enrolled in the study with a stocking density of 1.2:1 cow per bin (Table 1A, appendix). Cows were housed in a free-stall barn with 20 available cubicles in each pen filled with composted solid manure. Cows were milked twice a day in a 10 × 2 parallel milking parlour (Tecnozoo, Italy). Cows were fed a total mixed ration (TMR) in the automatic feed registration system (MooSystem, Cortes, Spain), and TMR was delivered twice a day coinciding with milking times (0700h and 1900h). The TMR was based on barley and ray-grass silage, alfalfa and ray-grass hay, straw, and feed concentrate (Table 1). Animals had ad libitum access to water through four individual and electronically monitored water-troughs (MooSystem, Cortes, Spain) in each pen. Cows were trained to the MooSystem before starting the study, and they were in different stages of lactation (DIM 170 ± 127.3) and parity (1.9 ± 0.99). Animals were allocated in an open barn that had a climate control system, and ventilators turned on according to relative humidity and temperature thresholds. The study was conducted in August 2019.

Table 1. Feed ingredients for the three locations AU, INRA and IRTA

AU	INRA	IRTA
Partial mixed ration Grass 28% Maize 27% Rolled barley 15% Concentrate mix 30% (rapeseed expeller, soybean meal, beet pulp and minerals)	**Separate access to the different components of the ration** 1st cut hay : 1.8 kg DM/cow/day Grass silage : ad libitum Concentrate mix (maize, wheat, barley, sunflower meal, rapeseed meal, bran, cane molasses, vitamins and minerals): 3.6 kg DM/cow/day	**Total mixed ration (fresh matter)** Alfalfa hay 12% Rye grass hay 6.3% Rye grass silage 11% Barley silage 20.4% Straw 1% Concentrate mix 49.3% (maize, wheat, canola meal, soybean meal, hydrogenated fat, wheat middlings, vitamins and minerals)

1.2.3 The feeding systems

1.2.3.1 Insentec Roughage Intake Control (RIC; AU)

The Insentec Roughage Intake Control (RIC) feeding system (Figure 1; RIC, Hokofarm, Marknesse, The Netherlands) registers the time a cow has her head in the feed bin and the change of weight of the feed during this time. When the cow is entering the bin, her ID is read from her RFID transponder placed in the ear tag by an RFID reader on the bin. The feed gate is controlled by a photocell that will register an entering time when the cow puts her head through the opening of the bin. When she exits, the light beam hits the transducer again, and an exit time is registered. The sensitivity of the photocell, i.e. the time between the break of the light beam when entering and the opening of the gate, can be adjusted and is set to 0.4 seconds at AU1 facility. According to the manufacturer, the accuracy of the weight scale is ± 0.1 kg. To the best of our knowledge, there is no available information on temperature and humidity range for the system accuracy.

Data output from the Insentec system consists of timestamps when the cow enters and exits the bin (datetime): a calculation of the visit time (s) and the change in weight of feed during this time period (kg). The Insentec bins require regular calibration and are manually calibrated with a 20 ± 0.1 kg weight, both when empty and when full, every month according to the Insentec calibration scheme.

Figure 1. Picture showing the front of the Insentec feeders (left), and the dividers seen from inside the group (right).

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1.2.3.2 BioControl CRFI system (INRA)

BioControl Control (BioControl, Rakkestad, Norway) and Record Feed Intake (CRFI; Figure 2) system consists of roughage feeders that automatically measure individual feed intake and the duration of the visit. As shown in Figure 3, access to each feeder (3) is controlled by an electronic gate (5) where cows are identified by an RFID sensor (7) and their ISO HDX ear tag (AllFlex, Vitré, France). The bin is placed on two weighing scales (4) and weighed every second. The feed bins are wired to electricity via an inverter, so that it will run in case of a power cut. Data are exchanged between the station controller (1) and a computer via an RJ45 cable. The station controller can store up to 7 days of data in case of a problem with the computer. The associated software on the computer also permits programming the access feed bins for the individual cows, depending on for example type and amount of feed. The records for individual feed intake and visit duration contain information on (i) the presence of a cow at the feeding bunk and her ID, (ii) the weight of the feed bin when the gate opens and (iii) the residual weight of the manger when the gate closes. The dataset includes continues timestamps (every 2 s), the ID of the animal at the feed bin, the position of the bin and the weight of the bin.

Figure 2. Biocontrol CRFI system in use.

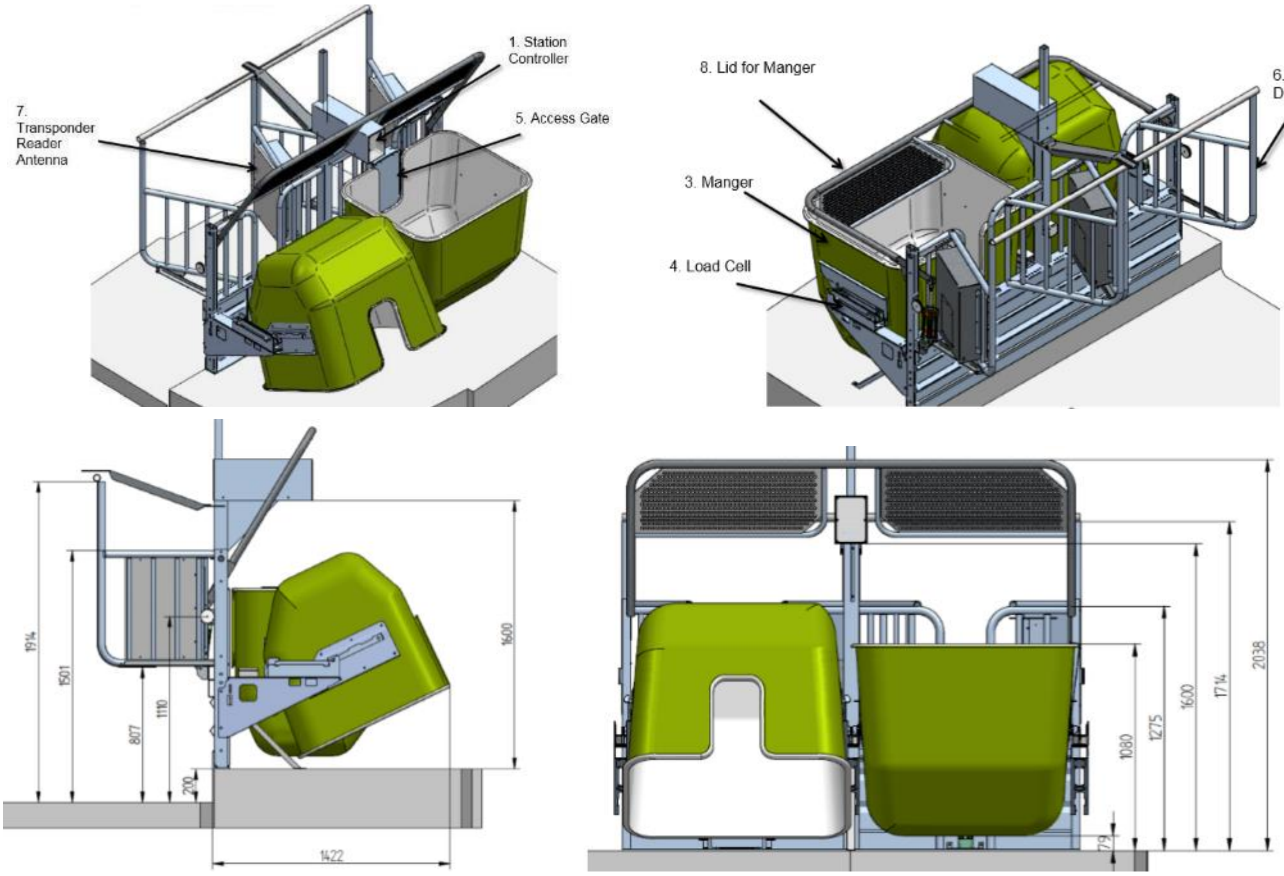

Figure 3. Description of the BioControl CRFI feeders.

1.2.3.3 The MooSystem (IRTA)

Access to the MooSystem Intake Control Feeding System (Figure 4) is controlled via an electronic gate, which records the time when a cow enters the bin and when she exits the bin. The system also logs feed intake by recording the change of weight of the bin during the duration of which a cow is present. The size of the bin is 90 x 70 x 90 cm, and each bin is standing on three load cells of 100 kg resistance per load cell. The bin's weighing capacity is 300 kg with an accuracy of 10 g. When the cow enters the bin, her HDX ULTRA ear tag (AZASA, Madrid, Spain) is read by the RFID transponder on the bin, and this RS-485 signal is converted into an Ethernet signal and sent to a computer for recording of data. The gate opens, as the photocell placed on the top of the lateral side of the bin detects the cow, and it stays open as long as the photocell placed at the bottom lateral side recognises the presence of the cow. To prevent errors due to displacements, i.e. when cows push each other out of the bin before the electronic gate is closed, a reading of the ear tag transponder is performed every 30 s, as long as the electronic gate is open. If the cow ID does not coincide with the expected one, the electronic gate will close and expel the cow. The data are shared over a cloud function, and an algorithm is implemented on daily basis to receive information about feed intake and visit duration. In order to collect precise data, the manufacturer recommends a monthly calibration using a 25-kg load. This calibration also permits to tare the load cell with the weight of the empty bin. To obtain reliable feed intakes, a weekly calibration is performed to ensure that there is no deviation of the measurement.

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Figure 4. Picture showing the front of the MooMonitor feeders (left), and the access gate seen from inside the group (right).

1.2.4 Behaviour recordings

The behaviour of the cows was recorded using direct observations by one person standing in front of the bins (AU and IRTA) and by video recordings (INRA). Two cameras (Axis M1065-L) were installed in front of the feeders at a distance of 6.5 m and a height of 3.8 m, and each camera recorded six feeders. The behaviour recordings during the direct observations were performed using a registration software that was time synchronised with the feeding system. Observations were conducted during different times of the day to include the busy periods right after delivery of fresh feed and more quiet periods when some time had passed after the last delivery of fresh feed. The observation periods lasted 89 ± 11.3 min, and were conducted at 7-9 am and 10 am-1 pm at AU, 81 ± 20.3 min and were conducted at 8-10 am, 11 am -1 pm, and 7-9 pm at IRTA, and continuously between 8 am and 9 pm at INRA. The videos were recorded using the Media Recorder 4 software (Noldus, The Netherlands), and the behaviour recordings from the indirect observations were analysed using The Observer XT 14.2 software (Noldus, The Netherlands). The video recordings and the Noldus software were time synchronized. The bin was observed from when a cow entered until she exited the bin, described in detail in the ethogram (Table 2). In addition, the time the cow was actually eating was also recorded, i.e. when a cow was taking bites when present in the feed bin (Table 2).

Table 2. Ethogram for behaviour registrations from manual observation and video recordings of lactating dairy cows eating from a feed bin

Event	Sub event	Description of event
Cow outside the feeding area		The cow is outside the feeding area/feed bin, and the gate is closed
Entering		The cow puts her head above the closed gate, and the gate opens
Eating, feed gate down, head in the feed bin	Head angled down, taking a bite	Muzzle not visible over the edge of the feed bin
	Chewing	Head elevated, muzzle visible over the edge of the feed bin, sideways jaw movements
	Not chewing	Head elevated, muzzle visible over the edge of the feed bin, no sideways movement of the jaw
	Other	Head elevated, muzzle visible over the edge of the feed bin, any other behaviours not listed above (feed tossing, licking the bars etc.)
Exiting		The cow moves back, her head goes back behind the opened gate, gate starts to close

1.2.5 Sample size and analysis

To estimate sample size, a previous dataset on the duration of feed visits was retrieved from the Insentec system and the BioControl CRFI system. The mean duration of a visit for the whole sample population is shown in Table 3.

Table 3. Sample distribution (s) in the dataset used for power calculation, 268 cows and 42581 cow days

	Insentec	BioControl
Number of animals	268 cows	40 cows
Number of cow days	42581 d	280 d
Max visit duration (s)	1426	3651
Q3 visit duration (s)	297	769
Mean visit duration (s)	222.3 ± 243.9	578 ± 900.5
Median visit duration (s)	133	397
Q1 visit duration (s)	56	191
Min visit duration (s)	6	31

The maximum acceptable difference (x-axis on graphic 1 and 2; Figure 5) between gold standard measurement and sensor data and the power of the analysis has an impact on Cohen's d coefficient and, as a result, on sample size calculation. A representation of the combined effect of the power and the acceptable difference on the number of observations to gather is therefore displayed in Figure 5. This was done using the R pwr.t.test procedure (R Core Team 2017, R Foundation for Statistical Computing, Vienna, Austria).

A power calculation (pwr.t.test, R Core Team 2017, R Foundation for Statistical Computing, Vienna, Austria) was conducted to decide sample size for the study, using the following function:

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apply(data.frame(q=(mq(seq(0.05,0.15,0.01)))/sq), MARGIN=1,FUN=function(q){pwr.t.test(d=q,power=p)*

where q = Cohen's d; m_q = mean for the sample population; the sequence 0.05-0.15 represents difference from the mean (%) that we want to detect; s_q = standard deviation for the sample population and p = the level of power to be tested.

Cohen's d was calculated as:

$$\frac{(\%\ difference\ from\ M_1) \times\ M_1}{pooled\ standard\ deviation}$$

where M_1 equals the mean of the sample population.

To take a possible variation in accuracy depending on visit duration into account, data were tested for each quartile with the power 0.5, 0.6, 0.7 and 0.8, and for 5-15% difference from the means (Figure 5). The calculation shows that for P = 0.8, approximately 1330 visits are required to detect differences of 5%, and for the power 0.5, approximately 650 visits are required (Table 4).

Table 4. Number of observations required for the Insentec system to detect a difference between means of 5%, 10% and 15%, for P = 0.5-0.8 for the quartiles Q1, Q2 and Q3, and Q4

Quartile	**Difference between means (%)**	**Power**			
		0.5	**0.6**	**0.7**	**0.8**
Q1	**5%**	653	833	1049	1334
Q2 & Q3		647	825	1039	1322
Q4		622	793	998	1269
Q1	**10%**	164	209	263	334
Q2 & Q3		163	207	261	331
Q4		156	199	250	318
Q1	**15%**	73	93	117	149
Q2 & Q3		73	93	116	148
Q4		70	89	112	142

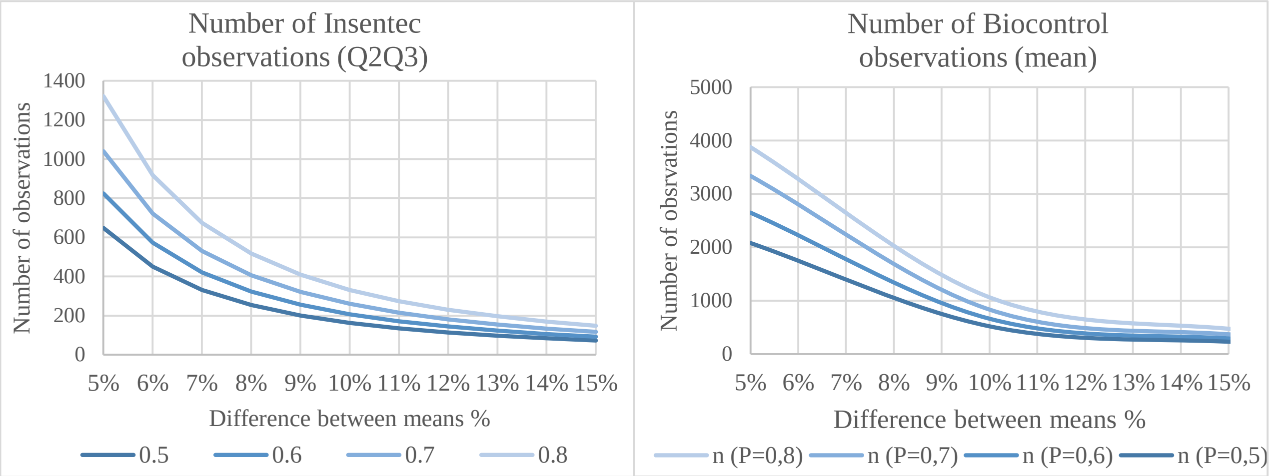

Figure 5. Number of observations needed to detect differences between observed and measured means by 5-15% for the power 0.5, 0.6, 0.7 and 0.8 for Q2Q3 (Insentec) and mean (BioControl).

1.2.6 Data handling and statistical analysis

1.2.6.1 Relation between observed duration in feeder (gold standard) and duration recorded by the system

We first aligned the time in data from sensors and from the gold standard observations/ recordings. More specifically, we looked for systematic bias in the detection of the beginning and the end of the visits. At INRA's facilities, although the clock from video recorders and that of the biocontrol bins were on universal time, a delay of 12 s was noticed. This was corrected by adding 12 s to the time stamp for each event detected by the BioControl system. The visit duration from the gold standard was calculated as the difference between the timestamps for exiting the feed bin and entering the feed bin (see ethogram, Table 2). The visit duration from the system was calculated as the difference between timestamps when the cow entered the feed bin and when she exited the feed bin.

The relation between visit duration from the gold standard and as recorded by the system was tested by examining the difference between the two. The first and last percentage of the observations of difference per location were considered outliers and removed from the data. Data for the observed visit duration (gold standard) were divided into the three intervals depending on duration: short durations (< 150 s), medium durations (150-599 s) and long durations (≥ 600 s), corresponding to the general quantiles of gold standard visit duration.

The difference between the automatically registered visit duration and the manually observed visit duration was calculated as:

Difference = System observations – Manual observations (gold standard)

For testing the difference between visit duration from manual observations (gold standard) and as registered by the feeding system, data were run in a mixed model in SAS (SAS 9.4, SAS Institute Inc., Cary, NC, USA) including the fixed effects of interval of visit duration as recorded by manual observations (short, medium and long), location (AU, INRA and IRTA) and the interaction of the two. Cow ID was included as random effect. Bland-Altman plots (Bland & Altman, 1986) were generated to illustrate the differences between the gold standard and as recorded by the feeding system by plotting each individual data point together with the mean difference in visit duration, and the 95-% confidence intervals for the three locations.

The final dataset for comparing the difference between the system registrations and manual observations consisted of 1427 observations. Due to missing values for 24 observations, the number of observations used in the statistical analysis was 1403 (data distribution in Table 5).

Table 5. Distribution of visit duration (s, gold standard) for the total number of 1403 observations in the final dataset for

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statistical analysis of visit duration as recorded by the equipment compared to the gold standard (manual observations).

		INRA	AU	IRTA
Quantiles duration of manually observed total visit duration (sec)	100% Max	3242	1510	1646
	75% Q3	680	501	317
	50% Median	226	309	165
	25% Q1	32	165	85
	0% Min	2	9	1
Total number of visits observed		924	244	235
Number of observed bins		12	56	39
Number of observed cows		12	91	60
Mean number of observations per bin ± Std		78.1 ± 19.68	4.4 ± 2.14	6.2 ± 8.29

1.2.6.2 Eating duration in relation to total visit duration

Eating duration per visit was retrieved by adding the duration of the two registrations for Head angled down, taking a bite and Chewing (see ethogram in Table 2). Total visit duration was calculated from when the cow entered the bin until she left. Observations with a very short total visit duration (< 10 s, 21 observations) were removed from the dataset, as the eating duration for these short visits mostly was 0 s. Because of the low number of long observations, the 1% longest durations (> 2333 s, 8 observations) were removed from the dataset. The total duration the cow was present at the feeder was divided into three intervals: short (10-149 s), medium (150-599 s) and long (≥ 600 s), corresponding approximately to the general quantiles.

To analyse whether the total visit can be used to predict eating duration, the duration of eating was tested in mixed models in SAS (SAS 9.4, SAS Institute Inc., Cary, NC, USA), including the total visit duration, location (AU, INRA and IRTA) and the interaction of location and total duration as fixed effects. Cow was included as random effect. To investigate if total visit duration would have had the same effect on eating duration, depending on how long the visit was, short, medium and long visit durations were tested separately. Regression plots including R^2 values and 95-% confidence intervals were created (using the REG and SCATTER plotting statements in PROC SGPLOT, SAS 9.4, SAS Institute Inc., Cary, NC, USA) to illustrate the relation between eating duration and total duration for each location and interval. Mean, standard deviation and number of observations for eating duration, total visit duration, difference between eating duration and total duration, and the difference expressed as percentage of total visit duration were calculated per location and short, medium and long visits were calculated using PROC TABULATE (SAS 9.4, SAS Institute Inc., Cary, NC, USA).

1.2.7 Ethics

All facilities (Danish Cattle Center (DKC), AU Foulum, Denmark, the unit Herbipole at INRA, France, and the Department of Ruminant Production at IRTA, Spain) are research stations with the aim to conduct feed trials and other research studies on cattle. The Herbipole (INRA) operates under the authorisation number C-15-114-01, and IRTA dairy farm has research station authorisation number GI-9900017. There is no general agreement for DKC (AU). This study did not include any invasive treatments; we did not expect that the use of the feeders would induce discomfort, pain or stress to the animals, and therefore no additional ethics declaration at the local or national animal ethics committee was needed.

1.3 Results

1.3.1 Relation between observed duration in feeder (gold standard) and duration recorded by the system

The duration of the visits expressed as short, medium and long visits affected the difference between gold standard and system (Table 6), showing a smaller difference for the shorter visits compared to the medium and long visits. The confidence interval was greatest for the long visits and shortest for the medium visits (Table 6), and greater for INRA compared to AU. The average difference between the gold standard (observed duration of the cow was present in the feeder) and the duration as recorded by the system differed between the locations with the system displaying longer visit durations than the gold standard for IRTA and INRA, and shorter for AU (Table 6; Figure 6). There was no effect of interaction.

Table 6. LSMeans ± standard error (SE) and 95-% confidence intervals for the difference in duration between observed duration in feeder and as registered by the system per location and observation of short (< 150 s), medium (150-599 s) and long (≥ 600 s) visit durations (s)

	LSMeans ± SE (s)	**95-% confidence intervals**		**F-value**	**P-value**
AU	-0.21 ± 0.14[a]	-0.49	0.060	38.66	< 0.001
INRA	-2.63 ± 0.29[b]	-3.20	-2.056		
IRTA	0.40 ± 0.19[c]	0.019	0.77		
Short (< 150 s)	-0.50 ± 0.17 [a]	-0.83	-0.16	4.28	< 0.05
Medium (150-599 s)	-1.03 ± 0.15 [b]	-1.32	-0.74		
Long (≥ 600 s)	-0.92 ± 0.21 [b]	-1.33	-0.52		

* Different letters in superscript within group and column indicate significant differences P < 0.05

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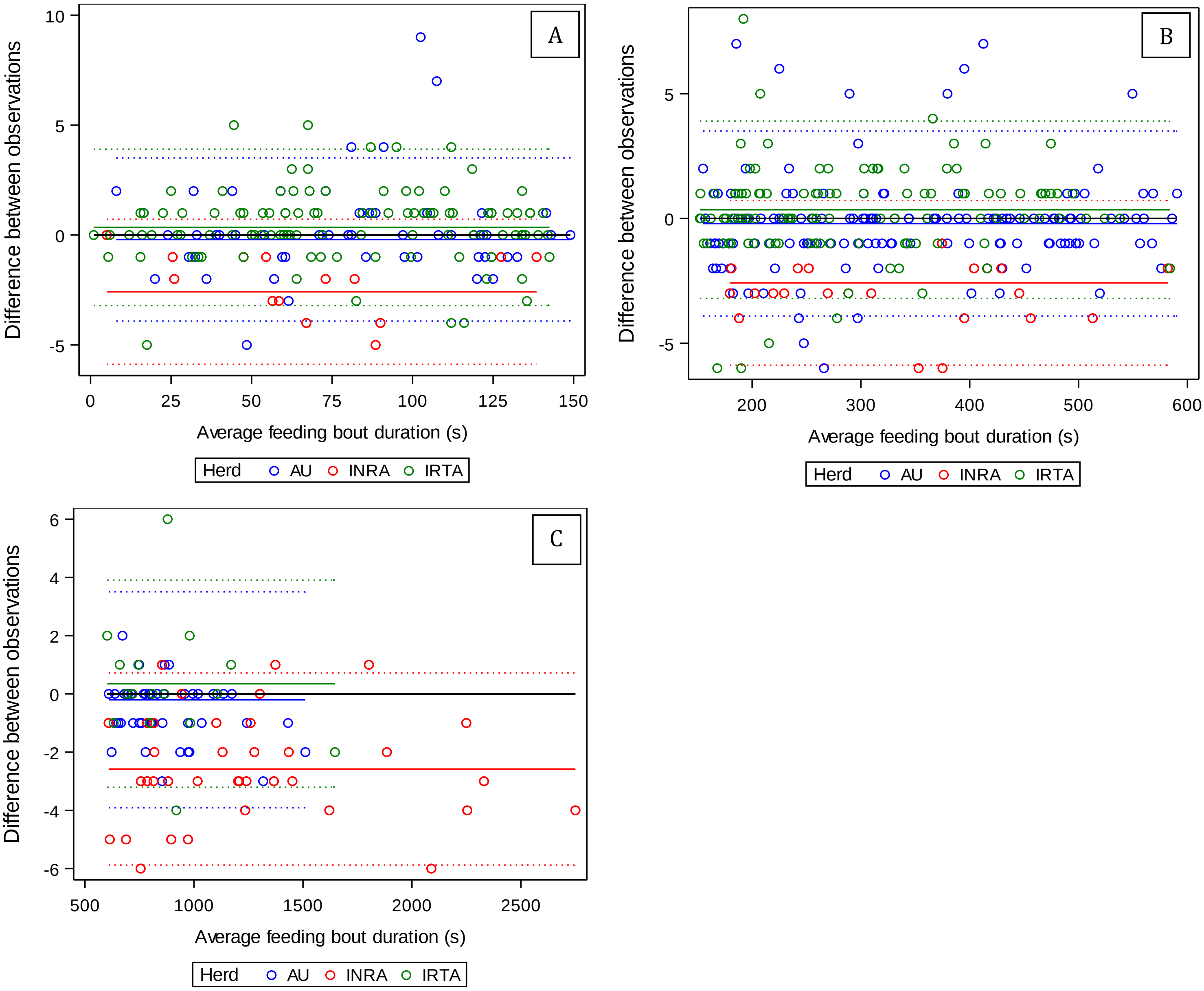

Figure 6. Bland Altman plots for short (< 150 s; A), medium (150-599 s; B) and long (≥ 600 s; C) visit durations. Perfect agreement, zero, is indicated by a solid black line. Observations from AU displayed in blue, INRA in red and IRTA in green. Solid-coloured lines indicate mean difference between duration from gold standard and from the system within location, dashed lines upper and lower 95-% confidence interval.

1.3.2 Eating duration in relation to total visit duration

The slope between total visit duration and eating duration was close to 1 for short, medium and long visit durations, suggesting a precise estimate of eating duration independent of the total duration of the visit (Table 7).

Table 7. Estimated eating duration ± SE, numerical degrees of freedom, probability values and the lower and upper confidence intervals for the intercept, and the total visit duration per short (< 150 s), medium (150-599 s) and long (≥ 600 s) visit duration.

Visit duration intervals	Estimate		95-% CI				P-values	
	Intercept	Slope	Intercept		Slope		Intercept	Slope
Short (< 150 s)	-9.1±3.11	1.00±0.035	-15.4	-2.78	0.94	1.07	< 0.01	< 0.001
Medium (150-599 s)	-12.0±5.88	0.98±0.016	-23.6	-0.14	0.95	1.02	< 0.05	< 0.001
Long (≥ 600 s)	-24.7±9.57	1.00±0.011	-44	-5.33	0.98	1.02	< 0.05	< 0.001

Eating duration differed between locations for the short visit duration interval. The cows at AU had the shortest eating duration per visit compared to the cows at both INRA and IRTA ($P < 0.05$; $F = 4.57$). Eating duration was plotted against total visit duration in Figure 7 to illustrate the relation between the two variables. There was no difference between eating duration and total duration for the long visit interval at IRTA, the R^2 value was 1.00 and no confidence intervals were estimated (Table 8; Figure 6). There was no effect of interaction.

Table 8. Means, standard deviation (std) and number of observations (n) for eating duration, total visit duration, the difference between the two and the difference expressed in percentage of total visit duration for the different location in the three intervals (< 150 s), medium (150-599 s) and long (≥ 600 s).

Visit duration intervals	Location	Eating duration (sec)		Total visit duration (sec)		Difference between eating duration and total visit duration (sec)		% of difference	Number of observations
		Mean	Std	Mean	Std	Mean	Std		
Short (< 150 s)	*AU*	73.7	37.71	82.6	36.08	8.9	9.95	14.82	36
	INRA	61.7	38.66	64.4	38.81	2.8	5.61	6.06	105
	IRTA	88.9	39.47	89.5	40.00	0.6	3.34	2.52	50
Medium (150- 599 s)	*AU*	328.1	125.25	345.4	124.12	17.4	24.96	8.99	107
	INRA	314.7	121.32	319.6	120.73	4.9	15.03	5.38	152
	IRTA	308.5	128.38	316.3	125.69	7.8	32.36	12.78	71
Long (≥ 600 s)	*AU*	845.4	226.80	871.0	225.02	25.6	26.88	3.42	60
	INRA	1161.4	409.72	1166.3	408.86	4.9	12.02	1.26	120
	IRTA	908.9	247.38	908.9	247.38	0.0	0.00	0.00	22

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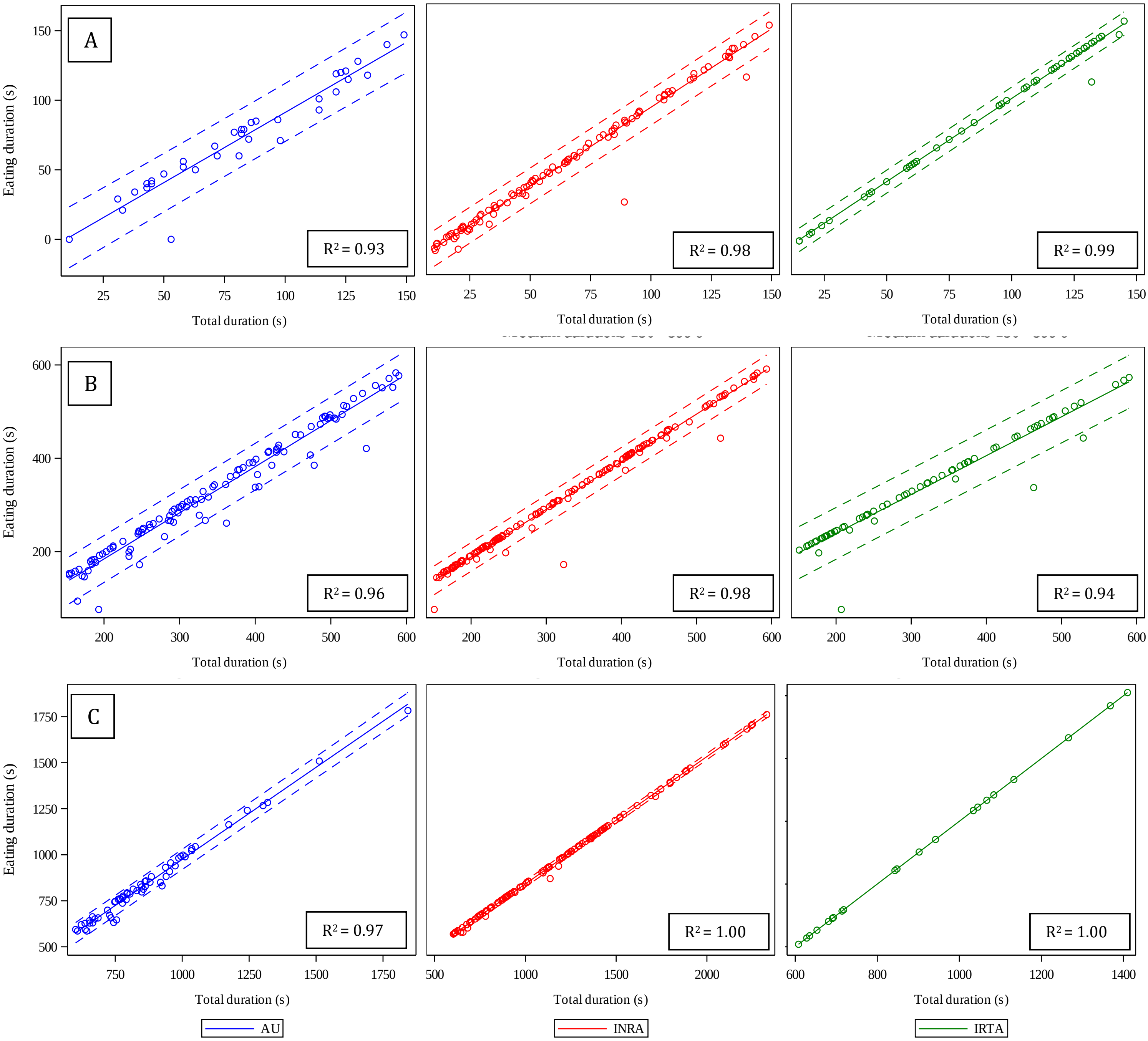

Figure 7. Eating duration plotted against total visit duration for each location and short (10-149 s; A), medium (150-599 s; B) and long (≥ 600 s; C) visit duration intervals. Observations from AU displayed in blue, INRA in red and IRTA in green. Solid-coloured lines indicate mean difference between duration from gold standard and from the system within location, dashed lines upper and lower 95-% confidence interval.

1.4 Discussion

Our assessment showed that even though the recordings of feed visits from the system and the gold standard overall displayed a strong agreement for the visit duration. There was a significant difference between locations in how precise the sensors recorded the visit duration, the difference between the locations, however, was very small and most likely not of biological relevance.

This could be due systematic biases such as inter-observer differences. For example, the observer at INRA recorded "Entering", according to the ethogram, when the cow put her head above the gate and the gate starts to open, and "Exiting" when the cows starts to back out, and gate starts to close. In the BioContol system, the timestamp for entering is recorded when the gate is fully opened, and exiting when the gate is fully closed, which would cause a delay of about 1-2 s. Since this was a small study, we did not perform an inter-observer or intra-observer reliability test, but this would of course be a preferred analysis to include in the report as stated in the guidelines.

We found a difference between locations in eating duration compared to total visit duration in the short visit interval. This could be related to the feed bin design, the type of feed provided or the feed bin stocking density, or due to inter-observer discrepancies, to mention a few. Feeding behaviour, in terms of visit duration, in relation to both stocking density and feed barrier design, was investigated by DeVries and Keyserlingk (2006), adding a partition at the feed bunk, creating feed stalls for the cows. When provided with feed stalls, cows spent longer time at the feed bunk, and the displacements and inactive standing time were reduced. The feed barriers in our study were similar but not identical between locations, which might explain the differences in eating duration compared to total visit duration between locations. The results suggest that accuracy in the estimates of duration of eating based on the visit duration may vary from facility to facility. This may be due to factors that do not relate to the technical equipment but also to, for instance, stocking density etc.

Feed visit duration in the Insentec system has previously been validated with a high correlation between manual observations and system recordings, but there are no published validation studies on BioControl CRFI or the MooFeeder system. Other available systems for automatic recording of feeding behaviour can be based on the same technology as the ones studied in this paper, or they might include a positioning system for estimation of feeding time or a technology to estimate chewing activity, to mention some. The Intergado monitoring system (AF-1000 Master), which is a similar feed intake recording system with individual feed bins on weighing scales, was validated by Chizzotti et al. (2015) and did also show a high association between recordings of visit duration by manual observations and the system. The GrowSafe system, which only registers when the cow is present at the feed bunk, was validated by DeVries et al. (2003). This system does not record feed intake but provides accurate measures of visit duration. There are other commercial systems recording presence at the feed bunk such as the CowManager SensOor system and the Track A Cow system which were validated by Borches et al. (2016), and they correlated well with visual observations. The MooMonitor+ (MooMonitor+, Dairymaster, Co. Kerry, Ireland) uses accelerometer technology to estimate feeding time with good correlation between visual observation and system recordings (Grinter et al., 2019). These systems are very useful for commercial farms, as changes in feeding behaviour might signal early-stage health problems, which will allow the farmer to implement timely interventions. However, since they only record the feeding time, either when the cow is present at the feed bunk or the movement during eating, any changes in feeding rate will be overlooked.

1.4.1 Sampling and data handling in relation to the guidelines

In relation to our power calculations, we included fewer observations than aimed at high power with a small estimated difference between gold standard and system observations. Given that, there was only a very small difference between our gold standard and the visit duration as recorded by the feeding system, the power calculation might not be fully relevant in this case. It is perhaps more important to focus on the biological relevance of any measured difference; a note that could be included in the SmartCow validation guidelines. The question of the relevance of P-values when testing for differences between observed and measured values has been discussed within other fields such as in medical studies and validation of lab equipment. This is also the case for the importance of presenting data not only in terms of probability of significance but also in terms of magnitude of the difference (Gardner & Altman, 1986).

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The datasets from the three locations differed in total number of observations as well as observed number of cows and bins and the duration of the visits. The longest, but also most of the short, visit durations were recorded at INRA, showing the large range in data distribution for this location. One reason for this could be that the recording of the gold standard differed for INRA; behaviour was sampled from video recordings instead of direct observations, facilitating sampling throughout the 24 h, which would explain the greater range. In addition, the total number of observations at INRA was greater, compared to the other locations, also allowing for a greater range. The range was reflected in the distribution of the data points we considered as outliers. For the dataset with eating duration in relation to visit duration, 20 of the short observations that were removed were sampled at INRA's facility and only one at AU. All of the removed long observations were sampled at INRA.

According to the guidelines, the data distribution should be taken into account when deciding the sample size, which we did consider when we designed the study. By including the intervals for the visit duration in our statistical analyses, we wanted to address this aspect and investigate if the system was more or less accurate depending on how long the cow visited the feeder. We chose to use the quantiles to divide the data into visit duration intervals to balance the sample size in each interval, and we found that the visits with a short duration showed a smaller difference between the automatic recordings system and gold standard than medium and long visit duration intervals in absolute values. However, expressed as percentage of the duration this was not the case, properly because the likelihood that a cow is not eating is larger the longer the visit. Anyhow, for all three facilities the difference were at a level that most likely have no biological significance when studying eating behaviour of mixed ration.

We aimed to collect data during different times of the day so that we would capture both long and short visits. However, when working with live animals not all factors can be controlled for, and the duration of a visit is difficult to decide beforehand. The duration of each visit may also be related to the equipment, management and housing in the respective location. For example, the cows in the location at IRTA were almost always actively engaged in eating while present at the feeder, whereas the cows at both INRA and AU performed other behaviours when they were at the feeders. In a study by Pahl et al. (2016), the possibility of using chewing time as a predictor for visit duration and feed intake was investigated by comparing visit time as recorded by the Insentec system with chewing behaviour. Similar to our findings, the study showed that there was a high accordance between eating duration, as measured by chewing duration, and total visit duration. However, eating duration in terms of feeding rate was affected by both stocking density, feed barrier design (Huzzey et al., 2006) and concentrate allowance (Henriksen et al., 2018). In our study, even though the difference between eating duration and total visit duration was marginal for all locations, we did see an effect of location, which again indicates the importance of clearly describing the environment around the equipment you want to validate. The greatest confidence intervals (CI) for short and long visit intervals were shown for AU, and eating duration was for some observations a lot shorter than the total visit duration. The smallest CI for short and long visit intervals was shown for IRTA; the R^2 value for IRTA was 0.99 for the short visit intervals, and there was no difference at all between eating duration and visit duration for the long interval. This difference between locations could be attributed to the different design; the edges of the bins on the feed bunk side at IRTA were more closed than at AU and INRA, limiting the cows' view of the surroundings and perhaps making them less eager to spend time in the bin.

We chose to focus our data collection on the individual bins rather than the cows, which is why detailed information of the cows was not included in the statistical models. For the validation of visit duration, we did not consider the stage of lactation or parity to influence how well the system could estimate visit duration compared to gold standard. On the other hand, it could be argued that eating duration in relation to total visit duration could be related to stage of lactation, body weight or parity, something that several other studies have investigated. For example, general feeding behaviour changes over the course of a lactation with increasing visit duration from early to mid-lactation (DeVries et al., 2003). In a study comparing total mixed diets containing either high or low concentrate/kg fresh matter, there was a large difference in feeding behaviour between cows, but there was no effect of stage of lactation on the visit duration (Friggens et al., 1998). Similar results were found by Azizi et al. (2009) where parity did not affect visit duration but indeed did affect eating duration in terms of feeding rate. In contrast to Friggens et al. (1998), stage of lactation had an impact on the visit duration (Azizi et al., 2009).

Feeding behaviour under competitive conditions (2:1 cow:bin ratio) for transition cows before calving differed between primiparous and multiparous cows where primiparous cows showed longer visit durations in a competitive environment, whereas multiparous cows showed a decreased eating duration per visit (Proudfoot et al., 2009). AU had a stocking density of 2:1 cow:bin ratio, and INRA had two cows per bin and feed content. Although cows in our study were lactating, we can assume that the high stocking density did affect their feeding behaviour, stressing the importance of always including information about the stocking density when validating feeding behaviour.

The objective with this study was to test if the guidelines for validating equipment that records cow behaviour, created in the SmartCow project, are useful for this purpose. To do so, we used the guidelines for a validation study of the different feed intake recording systems at AU, INRA and IRTA. In the first version of this report, relevant information was missing in the facility and data description from all three partners. However, when the information from the guidelines was provided in a table, creating a checklist for the user during the writing process, it was possible to produce descriptions of methods and materials containing the same type of information for all facilities (Table 1a, appendix). It is not possible always to include all aspects stated in the guidelines. For example, information regarding the robustness of the system, such as drift over time, is difficult to include unless the study runs over a long time. The asked information of "recoverability of the sensor" is not fully plausible to address when the validation concerns stationary equipment rather than animal-based sensors. The importance of synchronising the time between the gold standard and the system cannot be stressed enough, but even when this procedure has been properly implemented there might be inconsistencies in data output from the two sources as shown for INRA. This highlights the importance of always checking the data for dissimilarities and outliers before conducting any statistical analysis.

1.5 Conclusion

The results of the study show that duration of a visit to the feeder bins can be estimated with very high accuracy in all three facilities included in the study. Duration of eating can also be estimated with high accuracy although cows at AU spend more time not eating when visiting the feeders than cows at INRA and IRTA. The guidelines developed in the SmartCow project were a valuable tool when planning and conducting this validation study.

1.6 References

Altman D. G. and Bland J. M. 1983. Measurement in Medicine: the Analysis of Method Comparison Studies. The Statistician 32: 307-317.

Borchers, M. R., Chang Y. M., Tsai I. C., Wadsworth B. A. and Bewley J. M. 2016. A validation of technologies monitoring dairy cow feeding, ruminating, and lying behaviors. J. Dairy Sci. 99(9):7458-7466.

Chapinal N., Veira D.M., Weary D.M., von Keyserlingk M.A.G. 2007. Technical Note: Validation of a System for Monitoring Individual Feeding and Drinking Behavior and Intake in Group-Housed Cattle. J. Dairy Sci. 90(12): 5732-573

Chizzotti M. L., Machado F. S., Valente E. E. L., Pereira L. G. R., Campos M. M., Tomich T. R., Coelho S. G., and Ribas M. N. 2015 *Technical note:* Validation of a system for monitoring individual feeding behavior and individual feed intake in dairy cattle J. Dairy Sci. 98 :3438–3442

DeVries T. J., von Keyserlingk M. A. G., Weary D. M., and Beauchemin K. A. 2003. Measuring the Feeding Behavior of Lactating Dairy Cows in Early to Peak Lactation J. Dairy Sci. 86: 3354–3361

Friggens N. C., Nielsen B. L., Kyriazakis I., Tolkamp B. J., and Emmans G. C. 1998. Effects of feed composition and stage of lactation on the short-term feeding behavior of dairy cows. J. Dairy Sci. 81:2368–3277

Gardner M. J. and Altman D. G. 1986. Confidence intervals rather than P values: estimation rather than hypothesis testing. Br. Med J. (Clin. Res. Ed.) 292: 746-750.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N°730924

Grinter L. N., Campler M. R. and Costa J. H. C. 2019. Technical note: Validation of a behavior-monitoring collar's precision and accuracy to measure rumination, feeding, and resting time of lactating dairy cows. J. Dairy Sci. 102(4):3487-3494.

Henriksen J. C. S., Munksgaard L. and Weisbjerg M. R. 2018. Short-term responses in production and behavior during periods of change in concentrate allowance for dairy cows. J. Dairy Sci. 101(9): 7942-7953.

Huzzey J. M., DeVries T. J., Valois P. and von Keyserlingk M. A. G. 2006. Stocking Density and Feed Barrier Design Affect the Feeding and Social Behavior of Dairy Cattle. Journal of Dairy Science 89(1):126-133.

Pahl C., Hartung E., Grothmann A., Mahlkow-Nerge K. and Haeussermann A. 2016. Suitability of feeding and chewing time for estimation of feed intake in dairy cows. Animal 10(9): 1507–1512.

Proudfoot K. L., Veira D. M., Weary D. M., and von Keyserlingk M. A. G. 2009. Competition at the feed bunk changes the feeding, standing, and social behavior of transition dairy cows J. Dairy Sci. 92: 3116–3123

SmartCow: an integrated infrastructure for increased research capability and innovation in the European cattle sector, 2018-2022. Guidelines for validation of sensor output (Deliverable number D7.1). Horizon 2020 Programme, INFRAIA-02-2017 Integrating Activities for Starting Communities, Project ID: 730924. https://www.smartcow.eu/wp-content/uploads/2019/06/D7.1-Guidelines-for-validation-of-sensor-output.pdf ; 2019-11-01.

APPENDIX 1. Table 1a. Information to put in the description of a validation study (adopted from the guidelines).

Sensor technology	**AU (Facility DKC)**	**INRA (Facility Herbipole - Marcenat)**	**IRTA (Facility XX)**
Type of sensor technology	Feeding bins on weighing scales with RFID identification	Feeding bins on weighing scales with RFID identification	Feeding bins on weighing scales with RFID identification
Commercial name/ Company/ Version of the Sensor	Insentec Roughage Intake Control (RIC, Hokofarm, Marknesse, The Netherlands)	BioControl CRFI system (BioControl, Rakkestad, Norway)	The MooSystem Intake Control Feeding System (MooSystem, Cortes, Spain)
Sensor weight and size, mounting system	H x W x L: 115 x 90 x 85 cm (outside measures)	H x W x L: 100 x 137 x 140 cm	H x W x L: 90 x 70 x 90 cm
Recoverability	The feed bins are stationary in the barns for everyday recording of feeding behaviour. The RFID tags mounted on the cows for identification follow the animals throughout their life span but can easily be removed and programmed to another individual.		
Memory capabilities and battery life	N/A	Five days of internal storage per bin in case of a network problem	N/A
Sampling rate	The bin is weighed as the cow enters and exits, data granulation of 1 s	The bin is weighed every second	The bin is weighed every second
Data output and handling - **Nature and type of data collected**	Timestamps for entering and exiting, difference in bin weight between timestamps	The dataset provided by the system is constituted of the timestamp (every 2sec), the ID of the animal at the feed gate, the position of the gate and the weight of the manger	Timestamps for entering and exiting, difference in bin weight between timestamps
- **Data rate and timestamp/dating**	Timestamp (date time) for entering and exiting in 1 s resolution	Data are transmitted with 2 or 3 s resolution	Timestamp (date time) for entering and exiting in 1 s resolution
- **Data processing**	The cow ID is read from her RFID transponder by an RFID reader on the bin. The feeding gate is controlled by a photocell that registers entering time when the cow puts her head through the opening of the bin. When she exits, the light beam hits the transducer again, and an exit time is registered. The sensitivity of the photocell, i.e. the time between the break of the light beam when entering, and the opening of the gate can be adjusted and is set to 0.4	The individual feed intake recorded results from the association between (i) the presence of a cow at the feeding bunk and her ID, (ii) the weight of the manger when the gate opened and (iii) the residual weight of the manger when the gate closed.	The cow ID is read from her ear-tag with the RFID reader on the bin. This RS-485 signal is converted into an ethernet signal that is sent to a computer that records all the data. The data are shared via Dropbox, and an algorithm is implemented on daily basis to get the output.

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	seconds at Foulum		
- **Data calibration**	Monthly according to company recommendation: manually with a 20 ± 0.1 kg weight, for both empty and full bins	Recommended by company: Monthly with 15- to 25-kg weight, depending on the usual load of the cells. Calibration is made weekly at the facility with a 15-kg weight.	Recommended by company: Monthly with a 25-kg weight. Calibration is made monthly at the facility with a 10-kg weight. Tare once a day after emptying the feed-bin. Deep cleaning weekly including a real tare once a week.
- **Theoretical accuracy, resolution and range of measurement**	± 0.1 kg	± 0.1 kg or 0.03%	± 0.01 kg
Environment for the animal	Approximately 120 cows were present in the studied groups, 91 of them took part of the study	12 cows were enrolled	72 cows were included
- **Housing (including size, floor type, bedding, cubicle type, feeding area etc.)**	Free-stall barn, cows fed a partial mixed ration from 28 Insentec feed bins per group, and given up to 3 kg of concentrate in the VMS.	Light cycle is 12 h minimum, and, when natural light is less than 12 h per day, artificial lighting is used from 0600 to 1800h. The floor is cleaned at least four times daily.	Free-stall barn with 20 available cubicles filled with composted solid manure. Cows are fed a total mixed ration (TMR) in the automatic feed registration system (MooSystem, Cortes, Spain)
- **Milking**	The cows are milked in automatic milking systems (VMS, DeLaval, Tumba, Sweden) with one milking robot per group	Cows are milked twice daily (0630h and 1530h) in a Delaval herringbone 2 × 14 milking parlour	Cows are milked twice a day in a 10 × 2 parallel milking parlour (Tecnozoo, Italy)
- **Group size**	60 cows per group, 1:1 cubicle:cow ratio, 2.1:1 cows per feed bin	12 cows per group, 2:1 cows per feed bin	18 cows per group, 0.9:1 cows per cubicle, 1.2:1 cows per feed bin

- **Climate conditions**	The outside temperature range for the area was 4-21 ˚C with a mean of 13 ˚C, and the humidity ranged 73-95%, mean of 86% during the two study weeks. The barn is naturally ventilated with fans activated according to relative humidity and temperature thresholds	The barn is naturally ventilated with no thermostat control. The records for the study were done in June 2019.	The climate control system activates ventilators according to relative humidity and temperature thresholds. The records for the study were done in August 2019.
Environment for the sensor	There is no available information on temperature and humidity range for the system accuracy	There is no available information on temperature and humidity range for the system accuracy	There is no available information on temperature and humidity range for the system accuracy
Ethic and need for permission	N/A	Herbipole operates under the authorisation number C-15-114-01	IRTA operates under the authorisation number GI-9900017
Animals, feed and water - **Animals and feeding**	Feed is delivered four times a day at 06, 10:30, 14:30 and 18 h. They have ad libitum access to water through two water troughs (0.5 × 2 m) on two different locations per group.	Feed is delivered after morning milking (approx. 9:00), and the bin is refilled if necessary before afternoon milking (approx. 15:00) in order to provide ad libitum access to fresh feed. Cows have free access to water, with no control of the quantity.	Cows are fed a total mixed ration (TMR) in the automatic feed registration system (MooSystem, Cortes, Spain), and TMR is delivered twice a day coinciding with milking times (0700h and 1900h). Animals have ad libitum access to water through four individual and electronically monitored water-troughs (MooSystem, Cortes, Spain) in each pen.
- **Breed**	Holstein	Holstein and Montbéliarde	Holstein
- **Physiological status**	Lactating, mixed stage of lactation and pregnancy	Lactating, mixed stage of lactation and pregnancy	Lactating, mixed stage of lactation and pregnancy
- **Age**	Mixed parity	Mixed parity	Mixed parity
- **Diet**	PMR, with 3 kg of concentrate provided in the AMS	Grass silage and hay fed separately at the feed bin. Concentrate in the automatic feeder.	TMR was based on barley and rye grass silage, alfalfa and ray-grass hay, straw, and feed concentrate
Position of the sensor on the animal and need for a habituation period	Cows had been trained to use the Insentec feed bins before entering the group of lactating cows	All cows had been trained to use the BioControl Controlling and Recording Feed Intake (CRFI) system before the experiment	Cows were trained to use the MooFeeders before starting the study
How to measure/record the "gold standard"	Please refer to ethogram for detailed description		

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Sample size and analysis	Please refer to the section 'Data handling and statistical analysis' for detailed description
Robustness of the system in use	The different feed recording systems have been in place in each facility for several years. There are spare parts available, and the bins can be repaired if necessary. All of the systems are sensitive to power cuts (the BioControl system can store data up to 5 d, but the Insentec and MooFeeders cannot), but external devices can be added to prevent data loss in these instances.

2 Validation of the use of the CowView system to record the position and the activity of cows

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2.1 Introduction

The guidelines to validate the recording of cattle behaviour using sensors were already tested for measuring feeding behaviour (see companion report: A validation study of equipment recording cattle feeding behaviour by Ternman et al.). A second test was run for a Real Time Locating System (RTLS) detecting the position of the cows. The system tested is the CowView (CowView GEA Farm Technologies, Bonen, Germany), which is commercialised as a Precision Livestock Farming tool for dairy farmers, and protected under an international patent (Sloth, & Frederiksen, 2014). It has been in use for several years and during the EU-PLF project (2012-2016), it has been validated by University of Milano in another barn (Tullo et al., 2016). The obtained accuracy in the study by Tullo et al. (2016) was more than 95 % for the time-budget information based on the main locations of the cows (at feeding table, walking and standing in alleys, resting in cubicles). However, the accuracy of a positioning system depends on the configuration of the barn. Therefore, we conducted a specific study at the INRA experimental farm Herbipôle (INRA UE 1414) where the CowView system is in place, available for research studies on the farm. The present report describes how we used the guidelines to validate the accuracy of Cow View location system by comparing it to manual observations and to another already validated device. The final calculation of the performance of the system has yet to be done, so here we essentially report on the use of the guidelines, and less on the outcome of the validation study.

2.2 Materials and methods

2.2.1 Description of the equipment used

2.2.1.1 Sensor technology

The CowView is a Real Time Location System (RTLS) commercialised by GEA Farm Technology. Cows are equipped with tags (6 × 4.5 × 4 cm, 150 g; Figure 1, right) on a collar around the neck. The tag is maintained on top of the cow neck by means of a counter-weight (7 × 5 × 3 cm, 400 g; Figure 1, right). Each tag is set to emit a unique identifier. The tags emit signals in the ultra-wide band twice per second. The signals are captured by antennas fixed on the barn ceiling. The position of a cow is determined thanks to triangulation (Figure 1, right). If the tag stays within a radius of 15 cm for consecutive samplings, she is considered to have stayed in the same position then that position is estimated as the average of all points within the 15 cm radius. The manufacturer ensures an accuracy of less than 50 cm in the detection of a cow position, this was also reported in a validation study by Tullo et al. (2016). The device is connected to Ethernet to ensure perfect clock synchronisation using the Network Time Protocol (NTP), dating in the epoch time system. The data are sent by internet continuously to the manufacturer that processes them in real time.

A CowView system was installed at the INRA Herbipôle Marcenat experimental facility (part of Herbipole, UE1414) in February 2015. All cows (about 160 depending on the time of the year) are equipped with tags at the neck and 18 antennas are placed on the barn ceiling at a height of 5 m.

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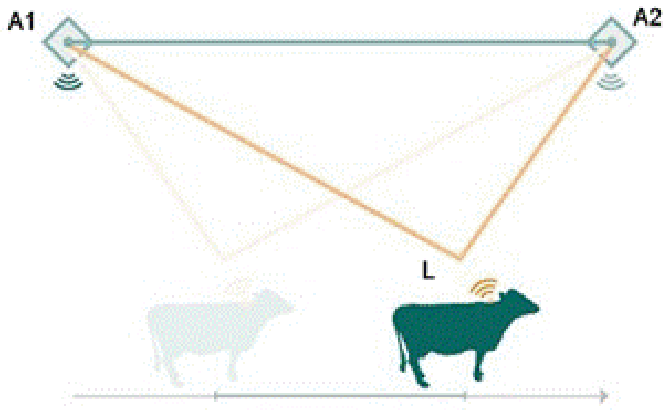

Figure 1. CowView tag on cow's neck (left). Position of the cow detected by triangulation (right).

2.2.1.2 Data output and handling

The limits of the different sections of the barn as detected with a tag were determined during the installation of the CowView system at Marcenat experimental facility. It allowed defining whether a cow is in the cubicle, feed bunk or alley sections of the barn.

The manufacturer infers the activity of a cow from its position: if the cow is found in a cubicle, it is classified as resting; if it is within the feed bunk zone, it is classified as feeding; otherwise it is classified as walking (if moving) or standing (if not moving) in alleys. There are four dataset generated by the CowView system, all as csv files:

- The raw dataset : tag ID/timestamp/x and y position at 2Hz
- The clustered position : raw dataset on which is applied a Kalman filter
- Continuous behavioural measurement : starting and ending timestamp of each activity done by a cow and recognized by the system
- Hour scaled time budget
- From this data it sends alarms to the farmer (here INRA) in case of hyper- or hypo-activity of the animals.

The data on activities calculated by GEA are sent back to INRA for experimental purposes. The raw data on cow position and the activities are stored in an INRA database.

2.2.2 Test environment

The CowView can be used only indoors because it needs antennas on the barn ceiling. The operating temperature ranges from - 40° C to + 70° C. The Marcenat experimental facility comprises of six pens. Each pen is equipped with 28 cubicles and can accommodate 28 cows (Figure 2).The floor is made of solid concrete scraped four times a day. The position of cows could be detected by CowView in all the six pens of the barn including the waiting area in front of the milking parlour, but not the milking parlour itself (total covered area, 41 m x 82 m; Figure 3). Whenever then antennas cannot record the location of the cow, such as when she is located in the milking parlour, her activity is recorded as “Unknown”.

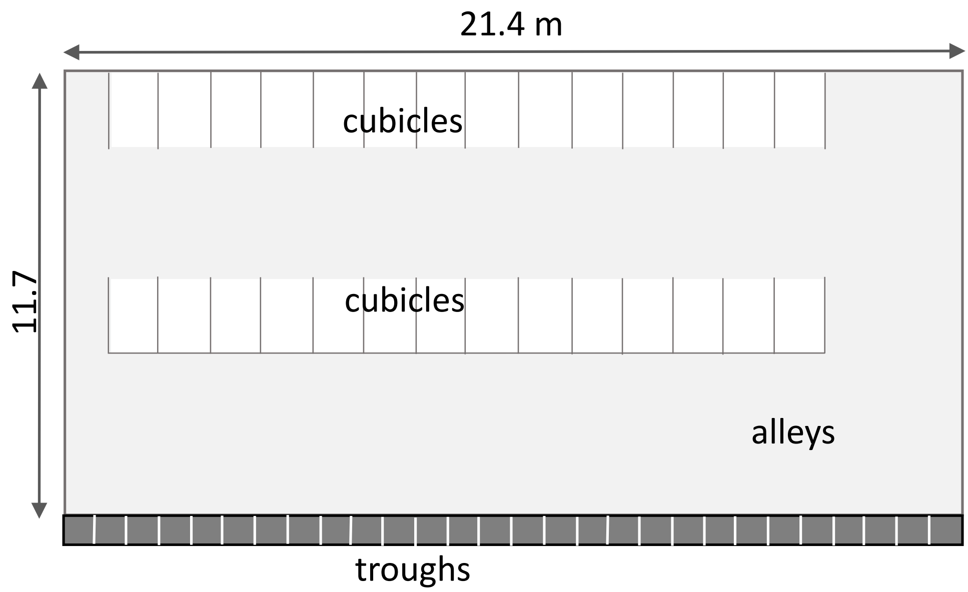

Figure 2. Design of a pen in the Marcenat experimental facility.

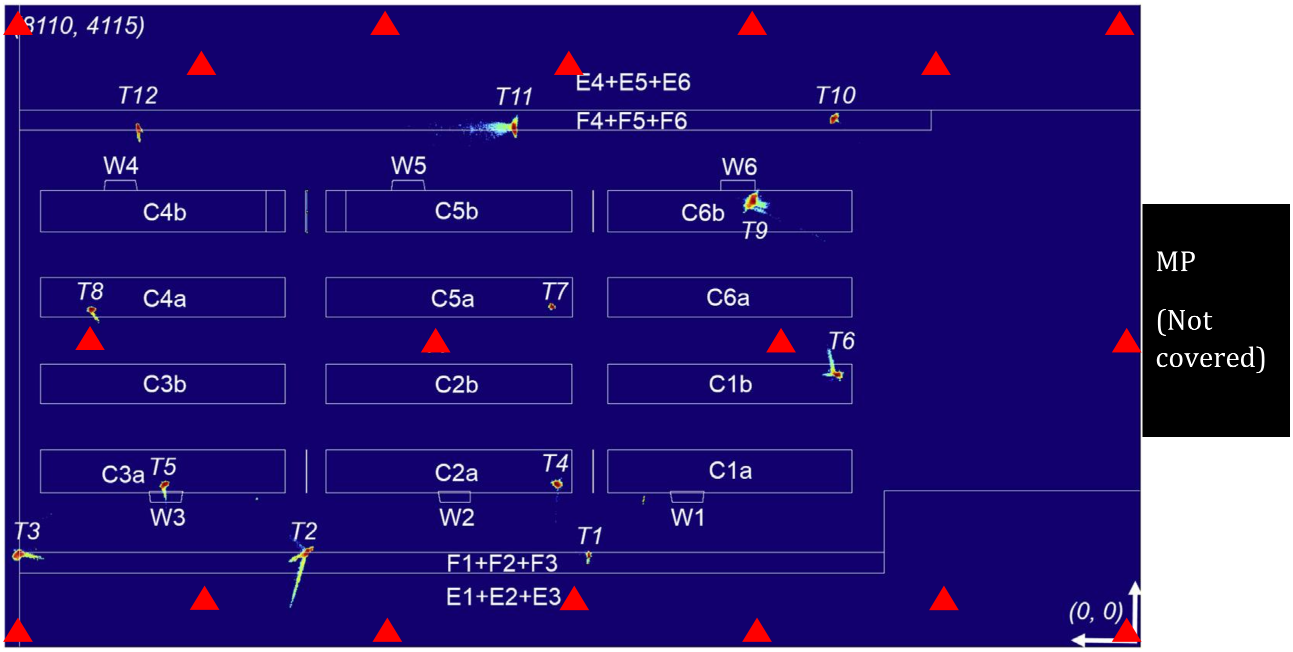

Figure 3. Virtual map of the barn drawn a priori. Lower right point is origin (0, 0) and upper left point is dimension in cm (8110, 4115). Red triangles represents the location of the 18 antennas. Each polygon is associated with an activity. C1a to C6b: cubicle of pen 1 to cubicle b of pen 6; W1 to W6: drinker of pen 1 to pen 6; F1 and F2: feeding table of pen 1 to 3 and 4 to 6; E1 and E2: extended feeding table of pen 1 to 3 and 4 to 6; A: alleys. MP: Milking parlour (not covered by the antennas) Additional information (not used by CowView) is given in italics. For validation purposes (see below), 12 fixed tags were positioned in the barn (T1 to T12).The position of the tags as detected by CowView is represented by colour density. The white arrows are 5 m. (after Meunier et al. (2018).

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2.2.3 Ethic and need for permission

The CowView system is a device commercialised for farms. The validation work does not need any permission from an ethical committee for experiment on animals because no handling of the animals is added to the routine management.

2.2.4 Animals and feeding

Primiparous (25%) and multiparous (75%) cows from the two breeds Holstein (n = 6) and Montbeliarde (n = 6) were included in this study. They were on average 267 days in milk, yielding 14.1 kg/d. The cows were housed in Pen 4 (see figure 3). They had ad libitum access to hay and to 15 kg DM of grass silage in separate troughs. They had access to one drinker.

2.2.5 Position of the sensor on the animal and need for an habituation period

The CowView collar is weighted and designed to carry CowView tag. The weight ensures the tag's positioning on the top of the cow neck, which is important for transmitting information of the cow's location. We do expect that if an additional equipment (e.g. a retro-mandibular microphone) is added on one side of the CowView collar then a counterweight should be placed on the other side of the collar, to ensure that the CowView tag stays on top of the cow neck.

The cows did not show any sign of disturbance when we equipped them with the CowView collar so no habituation seems necessary. Nevertheless, we recommend fixing the collars to the cows a week before the start of a study. At Marcenat experimental facility, cows are equipped with the collar as soon as they enter the barn. The cows recruited for this study entered the barn in November 2018, and were already used to wearing the collar.

2.2.6 Recording of a gold standard

Initially, we aimed at validating the absolute position of the cows by installing at least four video cameras above the pen and adding landmarks in the pen to be able to draw a grid defining 1.19 m^2 rectangular sections on the video screen thereafter. The dimension of each section (1.126 x 1.06 m) was chosen because it corresponds to a division of the pen size in 19 sections in the pen length and 11 in its width. In addition, the manufacturer guaranty a precision of 0.5 m of the position of a cow, which is close to the distance between the centre and the edges of a section. We would have considered the absolute position of the tag of a cow on this grid and estimated the observed position as the centre of the square. The underlying assumption was that with enough repetitions, the difference between the true absolute position of the cow and the measured position should be average to zero. The position of each cow was to be scanned every 5 min. However, this approach was too time consuming in regards to our limited workforce. It would also have resulted in figures of reliability that comprise of both the accuracy of the CowView system and of the error of the system due to attributing the position of a cow to the square she is present in as observed on the video recordings, instead of her exact position.

Due to these constraints, we used alternative approaches for validating the accuracy of the CowView location system:

- Attaching fixed tags to the barn interior (i.e. tags not mounted on cows; Figure 3), measuring the relative position of these tags in relation to specific points with known coordinates (cubicles, gates, troughs etc.) to define their relative x and y position.

– Comparing the activity detected as "feeding" by the CowView system with that provided by video observations (2 cameras in front of the troughs). We used data collected on 12 cows housed in Pen 4 on June 10, 2019 (see the document *A validation study of equipment recording cattle feeding behaviour* by Ternman et al. for further information).

2.2.7 Sample size and analyses

2.2.7.1 Fixed tags in the barn

We positioned 12 tags in pen 4 (Figure 3) to cover the entire area of interest. The tags were attached with the means to create optimal visibility by the antennas (< 100 m), so that a theoretical accuracy of less than 30 cm is attended when a precision of < 50 cm is desired. Data from the CowView system was collected over a consecutive period of 123 days. To check the stability of the triangulation during the 2015-2016 winter season, the relative position of each tag was manually recorded at one occasion (true position) and compared to the location provided by the CowView system.

For each time point, we calculated the distance from the manually recorded position to the mean position provided by CowView for each of the 12 tags. We considered that the precision would correspond to the maximum distance obtained on 95 % of the points, this metric named CEP-R95 being often used to characterize a positioning device. Then we visually checked the mean position of each fixed tag and their alignment, using the virtual map with the resolution of 1 cm (Figure 3).

2.2.7.2 Determination of "eating" by cows

A total of 491 visits were recorded both from video and Biocontrol for 12 cows in one pen during 16 hours.

First, we need to check if the signals from CowView and the video are synchronised. This is done by comparing the start date of events detected by the three devices using a radio-control clock. This operation needs also to be checked empirically to evaluate the potential derive of synchronisation (Meunier et al. 2018) which will be normally null if all devices stay connected to Ethernet.

Two types of analyses for determining the accuracy of the activity "eating" were planned:

– Qualitative analysis: at each time point, we will compare whether CowView and the video observations bring the same result (animal entering the feeding area vs. outside; for video observations: we will consider whether the animal has the head above the trough - the cow can be head down taking a bite of food or head up). This will allow us to calculate True positive, False positive, True negative and False negative from which the sensitivity, the specificity, the accuracy, the positive predictive value (PPV) and the F-score can be calculated:

$$Sensitivity = \frac{\text{True positive}}{\text{True positive} + \text{False negative}}$$

$$Specificity = \frac{\text{True negative}}{\text{True negative} + \text{False positive}}$$

$$Accuracy = \frac{\text{True positive} + \text{True negative}}{\text{True positive} + \text{False positive} + \text{True negative} + \text{False negative}}$$

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$$PPV = \frac{\text{True positive}}{\text{True positive} + \text{False positive}}$$

$$F - score = 2 \times \frac{\text{PPV} \ \times \text{sensitivity}}{\text{PPV} + \text{sensitivity}}$$

– Quantitative analysis: the difference in duration of feeding bouts (defined as a continuous period during which the animal has the head above the trough from video recordings) and that of similar bouts detected with CowView will be compared with the Bland & Altman method.

Again, we faced difficulties: To run such analyses, one needs to align feeding bouts detected by CowView and those detected from video. From the video, the precision is about 1 s (the time for an observer to process the information from the video and to type a code on a keyboard). By contrast CowView only informs about when an animal enters and leaves the feeding area with some imprecision. To overcome that difficulty, we decided to merge the data per 10 min periods so that we now compare the time spent feeding by each cow for each hour of observation. This also implies that we will run only a quantitative analysis.

2.3 Results of data analyses

2.3.1 Validation of the position of fixed tags

When comparing the true position of the 12 fixed tags and that provided by CowView, we found that for 95% of the observations, the difference between the true position and the CowView was 16 cm or less in all directions. We thus considered that in our experimental facility, the precision of the CowView in optimal conditions is 16 cm.

2.3.2 Validation of eating activity

The data analysis of eating activity is still in process.

2.3.3 Robustness of the system in use

The cows wear the CowView collar with its tag and counter-weight for all the period they are indoors (about 6 month per year). We have not detected any negative effect on the cows’ behaviour or wellbeing due to the collar since the installation in 2015 (four winter periods).

According to the manufacturer, there should be no drift in the detection in cow position. We see no reason for this not being true since the environment is still the same. There has been no additional installation in the barn since the introduction of CowView in 2015. However, a verification of the positions of both the fixed tags and the tags on cows is conducted every year by visually checking the density map (Figure 3) and according a specific procedure (Meunier et al. 2018). In addition, the manufacturer claims that there is no need for re-calibration of the CowView, but the manufacturer continuously monitors the device, according to their internal procedures.

The lifespan of the tags is 5 years without any maintenance, as stated by the manufacturer. We acquired the tags 3 years ago and none of them has had any failure.

2.4 Conclusions

The first results are very promising. In our barn, the accuracy of the positioning of fixed tags is 16 cm. We still need to compare the data from CowView with those from video recordings to check that animals are correctly detected when they are next to the troughs. The results will be included in an update of the present report.

2.5 References

Meunier, B., Pradel, P., Sloth, K.H., Cirié, C., Delval, E., Mialon, M.M., Veissier, I., 2018. Image analysis to refine measurements of dairy cow behaviour from a real-time location system. Biosystems engineering, 32-34.

Sloth, K. H., Frederiksen, D., 2014. Computer system for measuring real time position of a plurality of animals. WO 2014067896 A1.

Tullo, E., Fontana, I., Gottardo, D., Sloth, K.H., Guarino, M., 2016. Technical note: Validation of a commercial system for the continuous and automated monitoring of dairy cow activity. J. Dairy Sci. 99, 7489-7494.

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3 Feedback on the use of the SmartCow guide to validate sensors for the measurement of behaviour

Below are reflections on the use of the guide elaborated in SmartCow to validate sensors, and points to be included in the next version of the guideline:

1. The guide helped us structure our work and its description. It ensured that we did not forget important aspects.
2. The present document, that followed the guidelines structure, mixes:
   - The characteristics of the sensor to be validated (that is what we know about the sensor before any validation study)
   - What needs to be described when one carries out a validation studies
   - The validation per se (that is the results of the validation)
3. The guideline may be improved if the chapters were organized in the same order as a scientific paper.
4. We did not always strictly follow the order of sections of the guide; for instance, the information about the precision of the position detected by CowView as given by the manufacturer should in "data output and handling" but it was more logical in our case to give it in the section on "sensor technology".
5. A more detailed chapter on statistics and sample size should be included to improve the guidelines.
6. The guideline should be improved by adding more information about the importance of time synchronization between the various ways to record the information (e.g. the sensor and the video recorder). Even when the tools are synchronized, there might be a delay between systems. For instance, in the INRA barn, the video recorder and the BioControl troughs were both on universal time and this was checked before the experiment; Still, we systematically noticed a difference of 12 s between the two. This is essential to check this and to correct the data accordingly.
7. In some cases it is difficult to detect precisely the beginning and the end of an event with a sensor (e.g. with the CowView because the activity of an animal is derived from its position which is never 100% sure). In that case, it is merely impossible to align events recorded from video and from the sensor. Ways to deal with this issue should be included in the guideline.
8. In some cases, we noticed that the behaviour observed from the video and the data from a sensor (e.g. Biocontrol) did not match. In that case, it is essential to look again at videos and check if some events have been missed or if an animal was not identified correctly.
9. The video observations are very time consuming. It is also sometime difficult to identify correctly the animals.