UPPSALA UNIVERSITET

PROJECT REPORT

Detecting social interaction events between cows on a dairy farm

Torsten Malmgård, Björn Sparresäter

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Contents

Abstract

The purpose of this study was to use data from the the GEA CowView system (GEA Farm Technologies, Bönen, Germany) to detect avoidance behaviour between dairy cattle. The metrics investigated were: mean distance during a day, time spent performing the same activities and time spent within a certain distance from each other; but none of them showed consistent detection. Measuring time spent within a threshold could detect some friendly cows that followed each other around the barn. Another method investigated was displacement at the feeding area. This method was evaluated by an expert who deemed it to have an accuracy of 50% but stressed that on site confirmation needs to be performed. The method does not detect all displacement incidents but we believe that it can be helpful for behavioural zoologists studying cattle behaviour to save time when using video-recording.

1 Introduction

1.1 Background

This project is a part of a larger collaborative research project between the Swedish University of Agricultural Sciences (SLU), University of Copenhagen (KU), Dalarna University (DU), Wageningen University and Research (WUR), RISE Research Institutes of Sweden and Växa Sverige. The main focus of the general project is on how to improve animal welfare and health in dairy cattle production using sensor technology and is titled *"Precision livestock breeding — improving both health and production in dairy cattle"*. One of the goals of this project is to develop tools for summarizing animal movement and social interactions on dairy farms, thus our work should be considered as a complement to other research in this area.

Dairy cows are very social animals that frequently interact with their peers. These interactions can be both hostile and friendly and friendly interactions can include allogrooming while hostile behaviour includes kicking or headbutting. Hostile interactions can in many cases lead to displacement of the recipient where the aggressor takes the recipients place. Such interactions often takes place at the feeding area or other places where the cows compete for resources. The theory is that these hostile behaviour lead to avoidance where cows repeatedly avoid a known aggressor.

The algorithms and methods we develop to find avoidance behaviour can also be used in future research. A common approach when performing behavioural studies of dairy cattle is to record the population with video cameras, resulting in long recordings that has to be examined. Using our methods the search for interesting moments can be automated. A behavioural scientist can run data through our algorithms and get the time of an incident of displacement that could be confirmed later using video recording or direct observation.

1.2 Data

1.2.1 Real-time location systems and CowView

A Real-time location system (RTLS) monitors the position of objects in real time. CowView is an RTLS developed by GEA Systems using ultra-wide band radio technology. Each cow is fitted with a radio transmitter or tag and several receivers are mounted on different places in the barn, see Figure 1. The tags transmit a signal to the receivers several times each second and by combining the result from several receivers the cow's position can be triangulated with 50 cm accuracy [1].

The CowView data used has been collected at a farm in Sweden. CowView then processes the data from the RTLS to better suit our purpose. The system produces four types of processed data of which two (filtered positions [FA] and concluded activities [PA]) has been used in frame of this project.

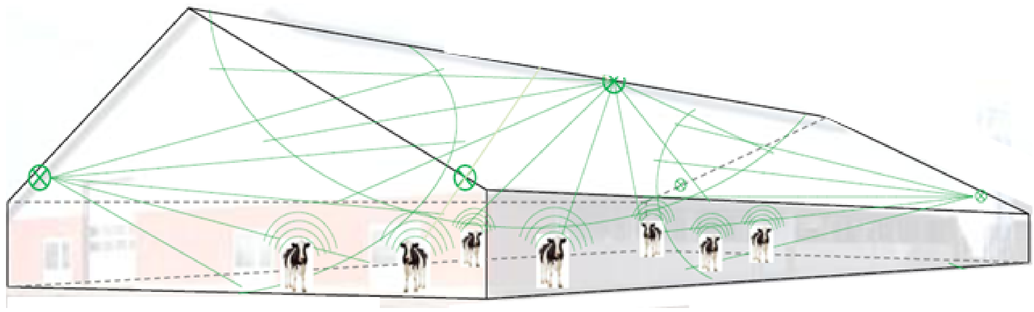


Figure 1: An illustration of the setup of the CowView equipment. Each cow is equipped with a radio transmitter that sends signals to a number of receivers mounted around the barn.

1.2.2 FA-data

The FA-data is the type of data that is the closest to raw data. Data are monitored each second, and each record consists of the cows position in x and y-coordinates in centimeters, a timestamp in epoch milliseconds as well as the six-digit id number of the sensor. The data also contains the hexadecimal string representation of the id and specifies that its FA-type data in each row to make data-handling easier. The hexadecimal number is used in the info-files described in section 1.2.4 to find the necessary information of the cow who wore the specified tag a certain week.

1.2.3 PA-data

The PA-data is a more processed higher level data based on the FA-data. The data is comprised of positional clusters where a new cluster is recorded whenever the cow has traveled 15 cm or 60 seconds has passed. As seen in Figure 2, the rightmost circle defines all the FA-points that gets implemented to one point of PA-data. These points gets clustered since the cow has moved 15 cm since the last cluster was recorded. The upper left circle defines a second cluster that is processed into another point of PA-data. In this case the points where all recorded and clustered since they take place within a 60 second time frame, without the cow traveling more than 15 cm. The data records each clusters position, start time, end time along with the id of the cow. In addition to this it also labels the activity that the cow is currently exercising. If there is any doubt when classifying the activity they are ranked in the following order:

1. *At the watering trough*
2. *At the feeding table*
3. *In bed*
4. *Out definitive*
5. *Walk*
6. *Unknown*

1.2.4 Additional information

A hexadecimal tag id is used to identify each sensor. However, a collar with sensor can be put on any cow. Therefore, to track individual cows rather than tags, there are separate text files containing the hexadecimal string of the tag, the id of the cow wearing it and information that the farmer records on each cow. Hexadecimal tag id is used to identify each tag. However, a collar with sensor can be put on any cow. Therefore, to track individual cows rather than tags, there are separate text files keeps track of which cow is associated to which tag and is updated for

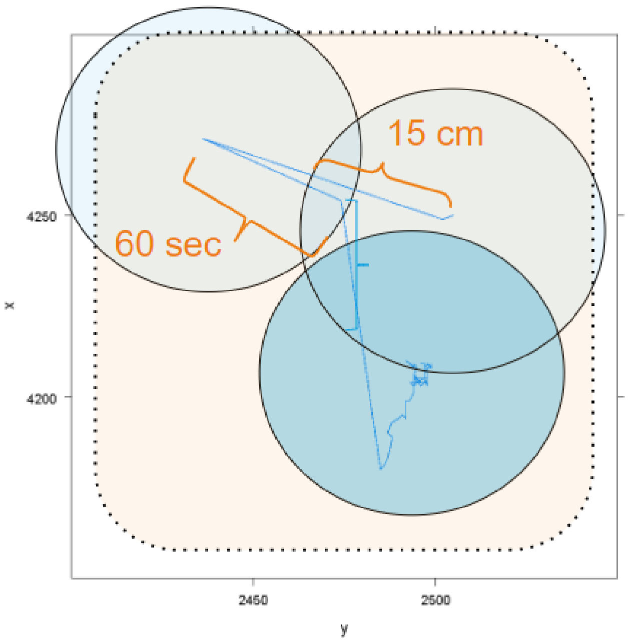


Figure 2: Method of clustering performed on FA-data to produce PA-data. The figure shows a cows path in the FA-data and the three circles representing the clusters that are formed by the FA-datapoints inside the circles. The clusters are limited both by a timeframe of 60 seconds since the last cluster and a positional frame of 15 cm since the last completed cluster.

every week. The information saved consists of the cows status, weather she is pregnant, lactating or soon to be slaughtered. The text files also contain the lactation number, i.e. the number of pregnancies the cow has had and the date of her latest calving.

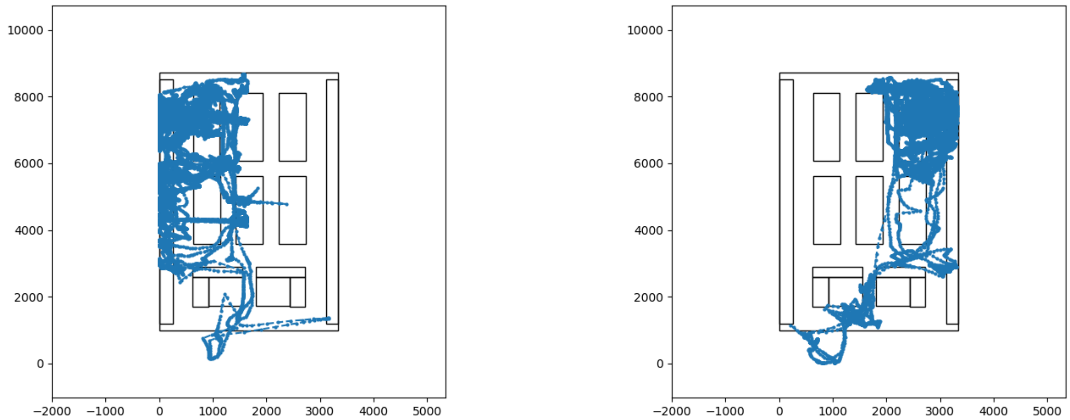
1.3 Pre-processing

The cows in the barn are separated by a wall that divides the barn into two parts. The cows belonging to different sides of the barn have limited contact between each other (see Figure 3) and it is therefore reasonable to investigate the relationship between cows inside each group separately.

As seen in Figure 3 the cows from different sides may interact when milking. The milking parlor is resided at the bottom of the barn to the left where both left-hand-side and right-hand-side cows are shown to be in the figure. It is unknown if the two populations are milked at the same time and sorted afterwards or if they are milked subsequently. Either way all cows are milked around 5am and 6pm and no cow ever change side after milking.

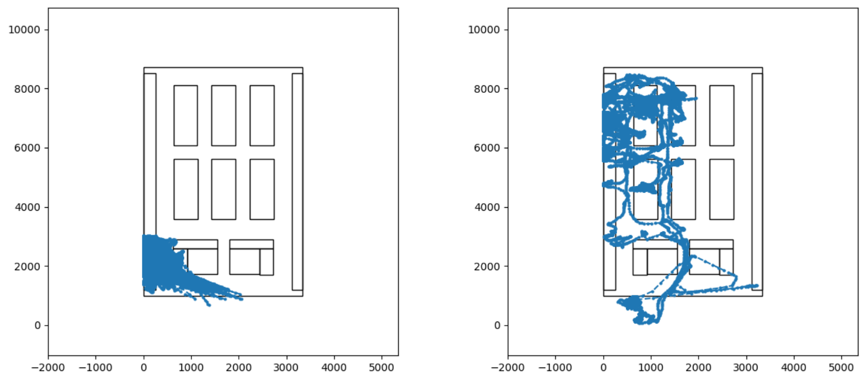
1.3.1 Inactive tags and sick cows

Some tags used to calibrate the positioning system and are known to be inactive, meaning they are not attached to a cow, and were therefore removed from the analysis. There is also an unknown number of inactive or faulty tags within the data set, these were filtered out day by day since a tag that is inactive on one day may be active on the next. These tags are filtered out by removing all tags that according to the data has not moved more than 35 meters along the y-direction of the barn. This also filters out cows that are placed in a separated room due to their health condition, these cows may be sick, late in their pregnancy or soon to be slaughtered. The movements of cows placed in a room would typically look something like the trajectory presented to the left in Figure 4 to the trajectory presented to the right in the same figure which displays a random cow with a more normal behaviour.



(a) (b)

Figure 3: Trajectories of two a cows residing in separate parts of the barn. The cow pictured in plot *a* are constrained to the left side of the barn and the cow in plot *b* are constrained to the right side. They both visit the lower left side of the barn for milking.



(a) (b)

Figure 4: Plot of two cows movement during a day. The one in plot (a) is displaying irregular behaviour while the one in plot (b) is displaying a more normal behaviour.

2 Methods

To detect avoidance behaviour we introduce three metrics. These metrics are chosen to be able to single out cows that show exceptional behaviour and plot these over time to verify avoidance behaviour. Each metric is displayed using a matrix where each row and column represented a cow and each position represented this particular cow-pairs score in the metric.

The analysis of the data is performed in Python. This programming language is chosen since it is already used in a lot of data analysis and has a plethora of useful libraries. We are mostly using the plotting library `matplotlib` since it is by far the most flexible plotting tool for Python with support for both animations and regular plots.

Lastly a database containing two weeks of test-data was also constructed using sqlite3. Sqlite is an efficient plugin allowing the user to fast set up a database for a project and is used broadly today for mobile apps and other projects. A full database containing all the collected data is under construction as this is written but not available for us to use yet. Building our own database and ensure our programs and algorithms was compatible seemed like the best approach to make our software maintainable. In the future, a scientist can use our software and directly load data from the completed database.

2.1 Metrics used to detect avoidance behaviour

The analysis is made in a trial-and-error fashion with three metrics implemented, tested and evaluated one after the other.

2.1.1 Mean distance

The simplest metric is the mean distance between to cows over time so that is the starting point. The labeled PA-data is used to filter out the distances where either of the two cows are labeled *In bed*. Therefore, mean distance in this case is the average distance between two cows when they are both active and walking around the barn. While a high score could indicate avoidance, there is really no way to make any conclusions from this metric since it does not tell anything about the two cows behaviour when they are close to each other and interacting.

2.1.2 Time spent performing the same/different activity

Next metric investigated was the activity of the cows. Using the PA-data we could see what activity each cow performed during a given time. Utilizing this we could check how each cow's daily routine coincided with the others, something that could indicate friendly behaviour. If two cows eat at the same time, sleep at the same time and drink at the same time they could be spending a lot of time together. This is of course to be used cautiously since activities can be governed by external events such as delivery of fresh food, night etc. Unfortunately the result showed very smooth results without any variation, making analysis hard, see Figure 5b.

2.1.3 Number of close proximity occurrences

Instead the FA-data was used to measure the total amount of time two cows spent within a certain distance from each other. A prolonged time in each others proximity could indicate friendliness although the distance limit must be chosen carefully and be subject of analysis. In this metric as well, the time spent resting was not included since two cows sleeping next to each other indeed could indicate friendliness but would skew the data.

2.2 Displacement at the feeding area

After examining the results of the threshold metric discussed above, the behaviour while feeding was investigated. The article by Val-Laillet et al. [2] describes the nature of displacement while feeding and its association with social behaviour. 48% of the cow-pairs investigated consists of subordinate cows repeatedly being displaced by dominant cows. The other 52% relationships are found to be unidirectional, meaning that both cows displaced each other at least once. This means that no conclusions of the large social structure can be drawn by monitoring displacement. Despite this, a noteworthy result is a finding of, on average, 20 incidents per cow and day. This can be used to compare the results of our method. Displacements could be used to draw conclusions on an individual level as well, giving hints on the relationship between specific cow pairs. The authors uses filmed video to reach their conclusion. We implement this using our data instead. This can be monitored by finding cows that eat, but move away when another cow comes to eat at the same place.

Val-Laillet et al. [3] defined displacement with the following sentence in their report, "A displacement involved direct contact (a butt, nudge, push, kick) with any part of the actor's body resulting in the complete and immediate (or within three seconds) withdrawal of the reactor's head from beneath the feed rail´´. While direct contact is difficult to determine using our data, especially since a more open and less crowded feeding system was used in the farms in this report, the time specified has been used to find incidents of displacement.

With the PA-data we do not only get the position of a cow at a given time but also the activity as explained earlier. The idea is that displacement can be detected looking for cows that are labeled *At feed* at one time and then *Walking* before once again being labeled *At feed* but at another position. If such a behaviour is detected, a search for surrounding cows is activated. The hypothesis is if there was a new cow very close to the first cow at the time that it started moving that the new cow may have been the cause of the relocation.

For each cow all data points, where the cow was not labeled as *At feed*, were filtered out, thus the remaining data only consists of data points were the cow is determined to be eating. Using the PA-data, which provides information of the *start* and *end*-time of all data points, a search was done on the remaining data looking for two consecutive points were the difference in time were between five and thirty seconds and the difference of the cows position in the y-direction of the barn were more than two meters. The gap in time and difference in position is used as an indicator of the earlier described behaviour where cows are eating before walking a couple of meters and then stop to eat again. These restrictions can be formulated as

$$5s \leq start[i+1] - end[i] \leq 30s, \tag{1}$$

$$200cm \leq |y[i] - y[i+1]|. \tag{2}$$

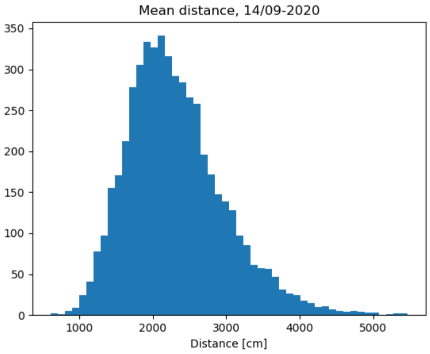
If two consecutive points does not meet these restrictions they are removed while the ones remaining are considered as possible cases of displacement. For these cases the end time of the first data point is saved along with its position. A new search are then performed going through all other cows in the data set looking for cows that have a data point which shows them starting to eat within one meter at maximum five seconds before the data that is saved for the original cow. If such a cow are found the tag id of the two cows involved is saved along with the time of the occurrence as a possible case of displacement.

The tag ids of the two cows involved in the detected case of displacement is presented to the user along with the timestamp. This information is enough for the user to recreate the incident using the animation tool which is useful to further investigate the incident.

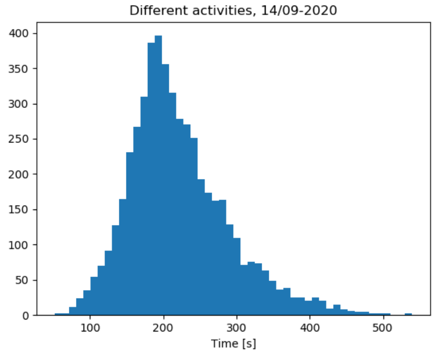
3 Results

3.1 Mean distance/Different activities

The histograms presented in Figure 5 show the distributions of the results from the metrics of mean distance and time spent exercising different activities during one day (the 14^{th} of September



(a)



(b)

Figure 5: (a): A histogram of the distribution of the measured mean distance between the different 5151 cow pairs in the left hand side of the barn on the 14^{th} of September 2020. (b): The same cows and day but the distribution of the measurement of time spent performing the same activities.

2020) for the cows located in the left side of the barn. A population of 102 cows were considered resulting in 5151 ($\frac{102*101}{2} = 5151$) possible pairs.

Ideally, a low mean distance in Figure 5a would indicate a friendly behaviour since it means that they spend a lot of time close to (or at least very little time far from) each other. However, further investigation showed that while some of the pairs that scored low in this metric actually showed some degree of friendly behaviour others just spent their time relatively close to each other without really interacting. We also found that these two categories where hard to separate based on mean distance alone. At the other side of the spectra, pairs with a high score never got close to each other and most of them just spent time at different parts of the barn. While this certainly is not friendliness, there is really no way of telling if it is avoidance since it does not tell us anything about how the cows would behave if they got close and became aware of each others presence.

For the metric measuring the time spent performing different activities the hypothesis was that a low score for a pair of cows would indicate friendliness while a high score would indicate some degree of avoidance. However, no such connection could be found. When investigating and comparing the pairs that scored at the opposite sides of the spectra no real difference in behaviour (in terms of friendliness and avoidance) could be found.

3.2 Time within threshold

Figure 6 shows a histogram of the distribution of the results from the metric *Time spent within threshold* for the 14^{th} of september 2020. Of the 5151 cow pairs 250 scored zero, meaning that they never got within two meters from each other during the whole day. Out of all call cow pairs all but nine scored between 0 and 5000 milliseconds and the remaining nine pairs is within the range between 5000 and 11500.

Comparing the cow pairs that score much higher than the overwhelming majority to a random "normal" cow pair and inspect their movements with the help of animations the difference is much clearer than for the metrics tested earlier. The best example of this comes from the data from the 19^{th} of November 2019 and the comparison is visible in Figures 7 and 8 which shows the distance over time for a random cow pair from the data together with the pair that, by far, scored the highest in the metric. The difference is obvious and when investigating the friendly cow pair further an animation of the two cows showed several instances of them following each other around the barn throughout the day.

Figure 9 shows the time spent within three meters for three different cow pair over the course of

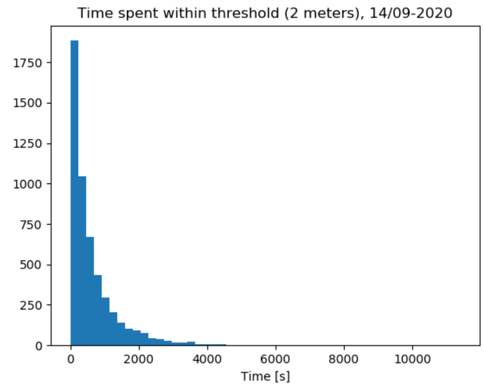
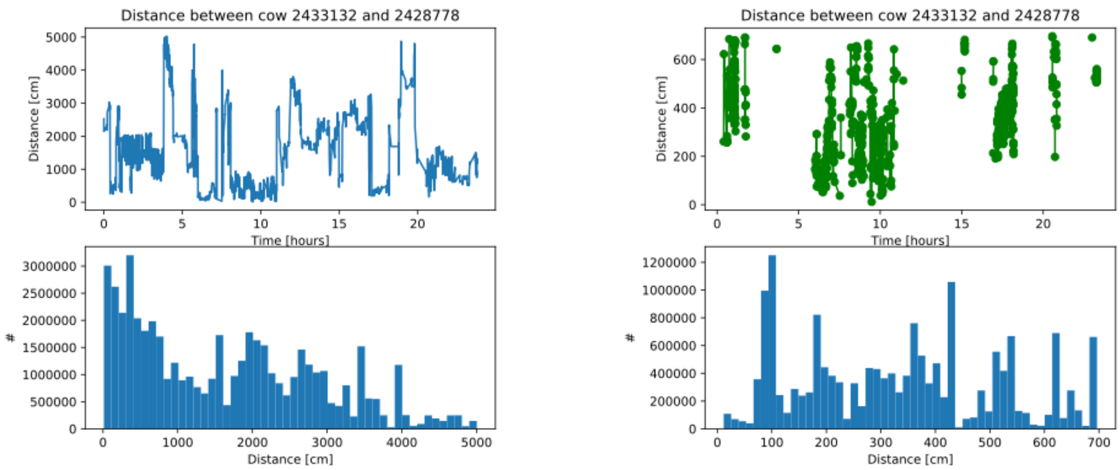
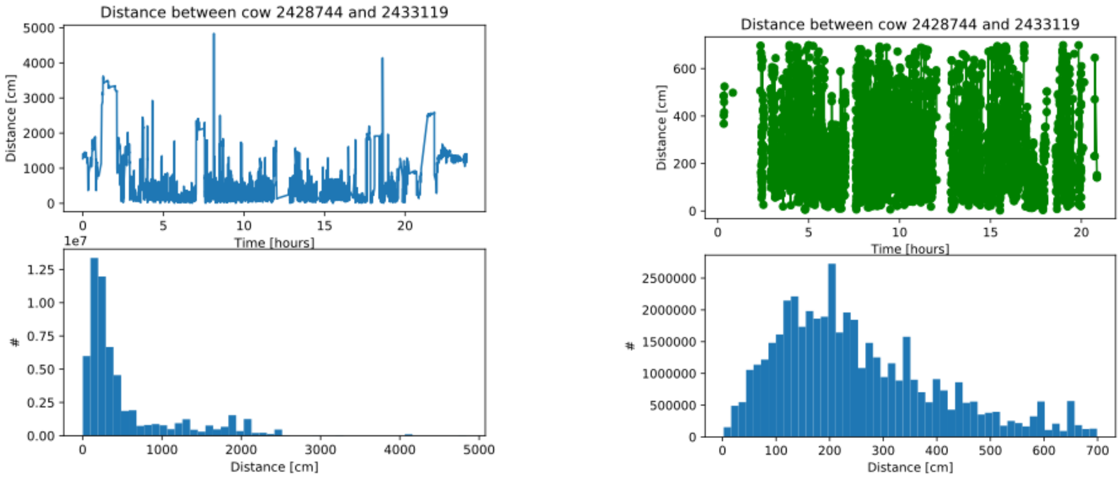


Figure 6: A histogram showing the distribution of measured time within 5 meters for the 5151 cow pairs on the left hand side of the barn. The measurement contains 250 instances of zero seconds and the maximum measured time within the threshold was 11402s



(a) (b)

Figure 7: Distance between two random cows over the course of one day. (a): The distance between the two cows during a day together with a histogram showing the distribution of the distances. (b): The distance between the cows during a day, only counting data where neither of the cows are asleep and when they are a maximum of ten meters apart and a histogram showing the distribution.



(a) (b)

Figure 8: Distance between two cows over the course of one day. The two cows were chosen specifically because they show strong signs of friendliness. (a): The distance between the two cows during a day together with a histogram showing the distribution of the distances. (b): The distance between two cows during a day, only counting data where neither of the cows are asleep and when they are a maximum of ten meters apart and a histogram showing the distribution

one week. As can be seen, the results can vary a lot from day to day. The figure only shows three cow pairs out of thousands possible and all of them were in the top ten of the results from the metric on a specific single day. The figure shows that some pairs of cows score more consistent on this metric while others pairs can score very low in one day before scoring extremely high on the very next day.

As stated above, this metric resulted in some extreme outliers with over 10000 seconds of recorded time together. These extreme cow pairs of this metric was investigated further by animating them. The result can be seen in Figure 10.

3.3 Overlapping metrics

An analysis of the overlapping between the metrics of *Mean distance, Time spent performing different activities* and *Time spent within a certain threshold* was performed on the data from the 14th of September 2020. The 102 cows who resided in the left side of the barn were the only ones considered and for each metric the top/bottom 100 cow-pairs which, according to the metric, showed the most friendly/avoidance behaviour were picked out. This resulted in three sets, each consisting of 100 cow-pairs. Each set was then compared to the others one by one, counting the number of pairs that were present in both sets. It should be noted that as many as 250 cow-pairs scored 0 for the metric of *Time spent within threshold* and that only 100 out of those pairs were picked out in this comparison and hence the overlap between it and the other two metrics in terms of avoidance should be considered with a hint of scepticism.

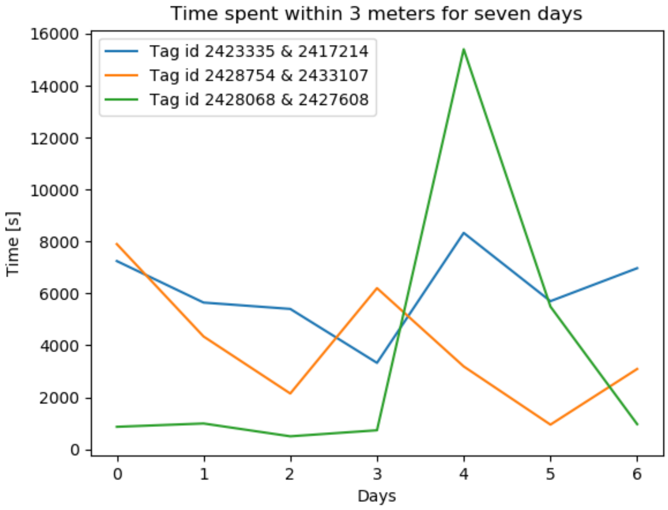


Figure 9: Time spent within three meters over seven days for three cow pairs that scored in the top 10 in at least one of these days. Some pairs (e.g. the one depicted by the green line) show varying results from day to day while others are more consistent.

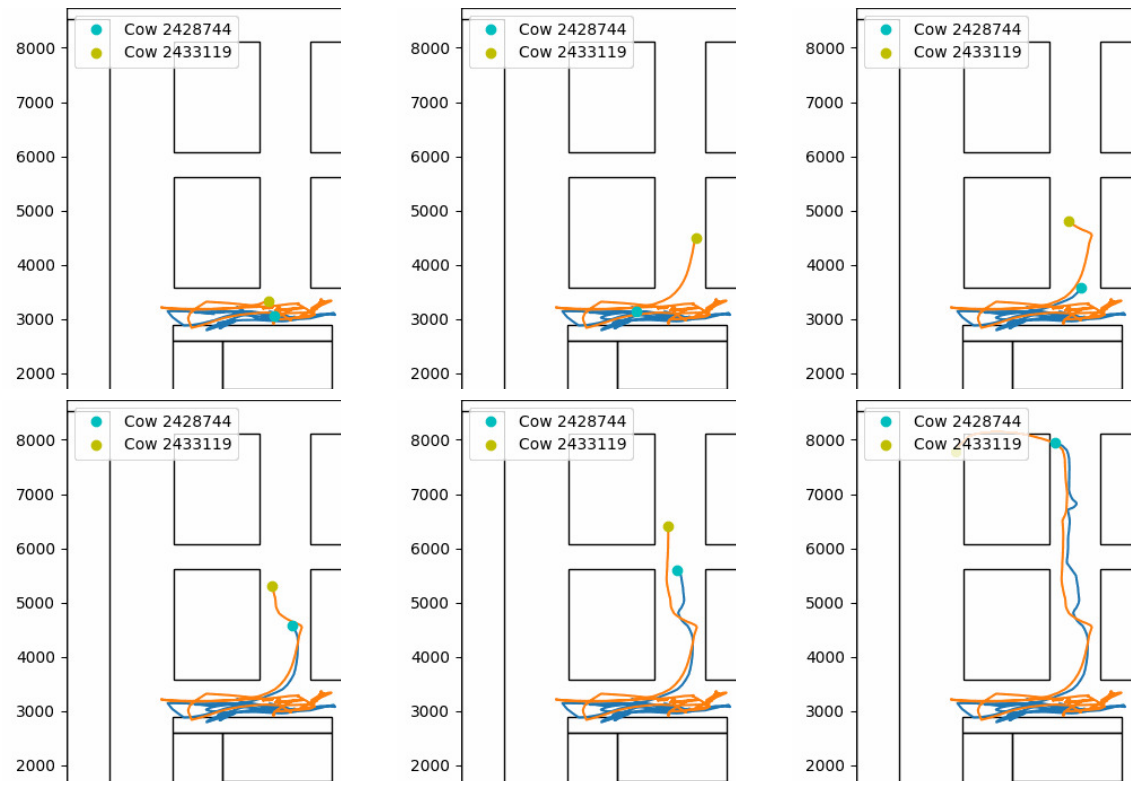


Figure 10: A series of images displaying an instance of two cows following each other which was found by our method. The sequence starts at the top left where the cows has been moving back and forth for a couple of minutes. The sequence the proceeds with the upper middle image and the yellow cow breaks away. The following images shows the blue cow following.

Metric 1	Metric 2	Friendliness	Avoidance
Mean distance	Different activities	0	9
Mean distance	Within threshold	20	16
Within threshold	Different activities	1	5

Table 1: Overlap in the results between the three different metrics, the numbers corresponds to the number of cow pairs that are present in the top 100 of both metrics, when looking at friendliness and avoidance.

3.4 Displacement at the feeding area

Since time within threshold could not detect avoidance, analysis of displacement was performed. The method detected an average of 12 instances of displacement per day.

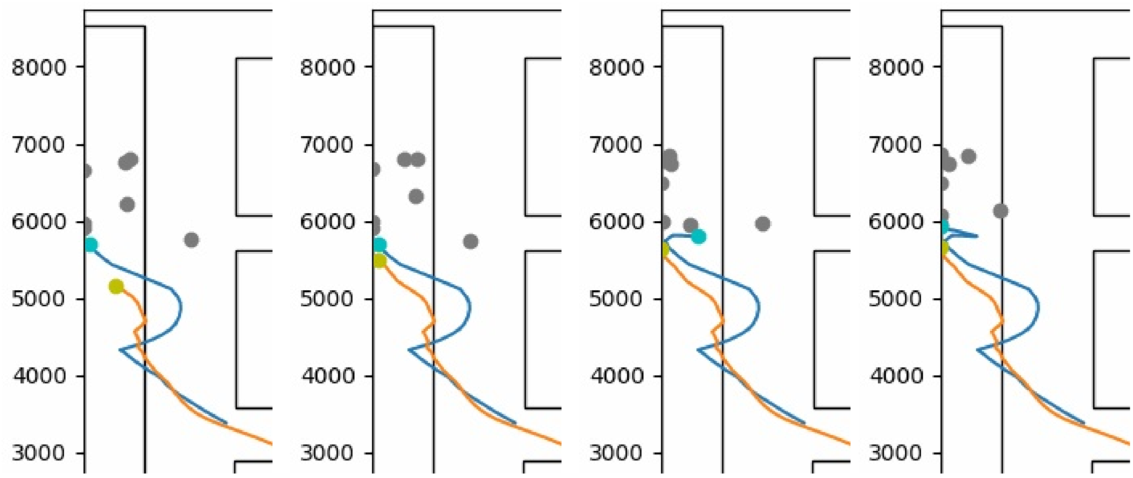


Figure 11: A series of images displaying an instance of displacement that where detected by the model. At the start (the frame to the left) the yellow coloured cow has just approached the blue cow who is eating. The following frames then shows how the blue cow moves away which indicates displacement.

All recorded incidents of the model during the 20th of September 2020 was used as a test-set. The incidents were animated with our software to 10 second long movies depicting 10 min of activity in the barn. These where sent to an expert for evaluation. These short movies where sent to an expert for evaluation. Figure 11 presents several snapshots from one of them. Out of the 16 recorded incidents the ruling was:

1. Possible replacement.
2. Possible displacement.
3. Possible displacement.
4. Probably just two cows meeting.
5. Same as 4.
6. Not displacement.
7. Not displacement. Possible positive interaction.
8. Possible displacement.
9. Probably just two cows meeting.

10. Hostile displacement.
11. Probably just two cows eating next to each other. Could be displacement though.
12. Replacement at feeding table.
13. Possible replacement.
14. Probably a random meeting. Maybe one cow is chasing away the other.
15. Crowded at feeding table. Not possible to determine the interaction.
16. Probably just two cows at a crowded feeding table. Possible displacement.

Where displacement means a cow moving another and replacement including the cow taking the others place. These statements are only made based on the short animations and need to be confirmed in a further study using video recording and analysis of individual behaviour such as ear and tail movement. With 16 samples and 8 correct determinations, our method gains an accuracy of 50%. This is an unreliable measurement since few samples where used and the experts verdict is reserved until confirmation on site can be performed.

4 Discussion

4.1 Friendliness

Our results from the *Time spent within threshold*-metric indicate that we can find cows that are friendly towards each other with our metrics. However, as shown in Figure 9, cow pairs that showed no proof of friendliness on one day can be very friendly the day after before spending almost no time together the next day. The figure also shows that some cows are more consistent in their behaviour towards each other but the dramatic changes in the results for some cow pairs is interesting. We do not know the explanation behind these changes but one explanation could be that the cows may be restricted in their movement around the barn in different ways during different days through interference by the farmer. That could be one explanation why the results vary so drastically but without knowing it is hard to say much about the metrics usability. We can find cows that consistently act friendly towards each other over time but in order to do that it is not enough to only consider data from a single day but it has to be for a longer period of time before any conclusions can be made.

Figure 10 shows some frames from an animation that was made in in order to investigate the extreme outliers of the *time within threshold*-metric. This animation along with several others showed clearly that these cows are following each other around the barn. This is an interesting result since it was found by our methods, showing that while it may not be reliable to determine the populations relationships, it does work when searching for cows who follow each other around during the day. What this means we do not know but its definitely a behaviour that is re-occurring in the data that could be investigated further.

4.2 Avoidance

Since cow pairs with a high score in our threshold metric can indicate friendliness, one could argue that pairs with a low score would show avoidance. This is however difficult to verify and hence our search for displacement is the only method showing avoidance behaviour that we could find. The method also shows promise in use for further research in cattle behaviour. Scientists often use video cameras to tape the cattle to later study the films and study behaviour. This can be very tedious since the recorded film is taped 24-hours a day, all week. Our method of detecting displacement can indicate some interesting times that should be further investigated in the taped material. A behavioural zoologist could save hours of time by skipping forward in their recordings to the incidents the method highlights.

The method detects on average 12 incidents per day for the 107 cows residing in the left hand side of the barn. Comparing our results with Val-Laillet et al. [2] and their find that a cow is involved in a displacement activity 20 times each day makes our data seem very inadequate. There are a few caveats though. First, Val-Laillet et al. used another feeding-mechanism with individual feeding places that could only be occupied by one cow at a time. This makes displacement more frequent since a cow needs to displace another to change food source. Since the farm used in this study has open feeding tables, a cow who wants to steal food from a neighbour only need to move over and share it without displacing the neighbour. Secondly, Val-Laillet et al. was able to confirm their findings with video-recording which was monitored by a human. There is no intention or accurate possibility of our model to perform better than a human evaluating video footage. Our goal was to develop a method that could aid scientist using video recording. This is something we achieved.

One could still argue that the method misses important interactions, and due to the large difference between our findings and those of Val-Laillet et al., this is probably true. However, if we where to adjust the parameters of our search and introduce more slack in the variables, it could in fact result in a lower accuracy. This means that changing our parameters to find more incidents that does not get detected by our current settings could result in a larger rate of false positives. This means that if we for example increased the time a cow must be displaced from feeding before returning to be detected, a larger amount of incidents would be detected, but since no parameters where decreased, the accuracy would, at best, be the same. One must also take into account the purpose of the tool, to save a scientists time. If we manage to introduce more slack to our variables to detect more incidents without lowering the accuracy, there is a risk of detecting incidents that does not look as a displacement, though correctly detected. If the accuracy then is not 100%, a scientist could be forced to look through more detected incidents in order to be sure to find something relevant to pursue. In this case, it would be more beneficiary to present a few, clear displacement incidents without much noise to filter through. Of course all this is speculations and it would be interesting to investigate this further.

In our studies, we planned to investigate velocity vectors of the cows. Since we have precise recordings of every cows position and at what time this was registered. We could construct vectors displaying the cows speed and direction of movement. To analyse these vectors and their impact on cow avoidance would have been interesting but there was not enough time to pursue this within the scope of the project.

5 Conclusion

Performing accurate classification on cattle using positioning data is difficult and must always be confirmed with direct observation and video recording to be accurate. While mean distance and time spent performing the same activities is not very good to make conclusion from, time spent within a threshold can detect friendly behaviour. It is easier to detect friendly behaviour than avoidance. Preliminary results show that our method has a 50% accuracy after expert evaluation..

6 Acknowledgements

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