# Validation and application of an indoor localization system for animals

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## Abstract

Tests for validating a system for continuous localization of individual animals in their residence environment are described. The positioning system consists of fixed beacons mounted in a cattle barn. Animals are equipped with an electronic label attached to a collar. All beacons emit a low-frequency signal that is received by the labels. Each label measures with an adjustable frequency the strength of the received signals and passes this information via a UHF signal to an antenna connected with a processing computer. Here the location of the label (and animal) is calculated. The overall average accuracy of the system was 30.5 cm with a standard deviation of 25 cm. The accuracy was negatively affected in the proximity of iron obstacles (walls, feeding fence). However, the obtained results offer sufficient perspectives to use the system for recording and analysing behaviour of individual animals. Observations showed that with the information from the system animal behaviours classified as 'in cubicle', 'on slatted floor' or 'at feeding fence' could be monitored continuously. Obtained accuracies for the behaviours were 95.1% for 'staying in cubicle', 91.9% for 'staying at feeding fence' and 88.5% for 'staying at slatted floor'.

**Keywords:** localization system, system accuracy, monitoring animal behaviour

## Introduction

In 2011 the project Smart Dairy Farming (WUR, 2011) started working on instruments, systems and sensors assisting farmers in monitoring and managing their animals better with respect to animal health and well-being. The instrumentation should help the farmer in his daily management in focussing on that processes or animals that need special attention. This should result in an increased profitability of the farm and better animal health and welfare. One of the tools that is used within the Smart Dairy Farming project is a cow positioning system. The system is able to determine the real time position of each cow inside a cow house. The position of the cows can easily be found on a map of the cow house which is displayed on a pc or smart phone. The main objective of the system is to support the finding of cows that need to be inspected, treated or milked. Besides finding cows other applications of the positioning system might be possible. Not each application of the positioning system requires the same accuracy. For just searching a cow inside the cow house an accuracy of about five meters might be sufficient, while a higher accuracy will be needed for determining behaviour or interactions of cows. Gygax *et al.* (2007) showed that an Abatec positioning system based on radar technology with an accuracy in a range between 0 and 0.5 meters could be used to track cows and to monitor social interactions. Huhtala *et al.* (2007) stated that for monitoring cow behaviour an accuracy of about 1 meter was needed for the position measurements. The research discussed in this paper has two objectives, 1) validation of the positioning system by determining the overall accuracy and quantifying effects of system configuration and barn lay out on the accuracy and 2) exploring the potential of the system for obtaining behavioural information from individual animals.

## Material and methods

<u>Description of the positioning system</u>
The positioning system is developed to determine the position of cows inside a cow house. The system consists out of beacons, labels and a processing computer which together determine the position of the cows. The beacons are placed at fixed locations in a cow house, with a maximum distance between each beacon of approximately 25 meters. Each beacon sends out a continuous signal with a fixed strength at a unique frequency in between 49 kHz and 55 kHz. These unique frequencies are used to determine which signal is send out by which beacon. Low frequent signals are used, because they do not need a line of sight and are less sensitive for disturbances in the signal caused by reflections. The labels are attached to the collar of the cows. It measures the arrival strength of the signal from each beacon and sends this information to the processing unit with an ultra-high frequency. The ultra-high frequency makes it possible to send this information to the processing unit over a distance of 100 meters, so every label in the cow house is able to send its information to the processing unit. In the test set-up the information was send to the processing unit one time per second. The processing unit uses the information about the signal strengths to determine the position of the cows.

<u>Set up of the system in the test barn</u>
Experiments were performed inside a cow house which was used for calves. The lay-out and dimensions of this cow house are shown in Figure 1.
The positioning system that was used in the measurements consisted out of six beacons, twelve labels and a processing unit. The beacons (yellow circles) were mounted at a height of 3.50 m at the wall of the cow house. Positions, from position measurements as well as real positions, were expressed with an x- and y-coordinate with the origin in the upper left corner of the cow house (red dot). The x-axis was parallel and the y-axis was perpendicular to the feeding alley. The distances between the beacons in x-direction was about 6 m and in y-direction about 10 m.

Additionally a calibration of the positioning system had to be performed. In this procedure the strength of the signal from each beacon is measured with a label on different positions inside the cow house. Each calibration position is pointed out by hand on a map of the barn and used by the system to improve the accuracy of the position determinations. There should be at least one calibration point under each beacon and in each corner of the cow house. The calibration points under the beacons are used by the system to determine the positions of the beacons. The calibration points in the corners of the cow house are used to determine the boundaries of the area in which the labels (and cows) stay.

Static accuracy tests

Static accuracy tests were conducted in a pen for 12 calves, which was part of the cow house (Figure 1: section B within the right red dashed rectangle). During the static experiments no calves were present in this pen.

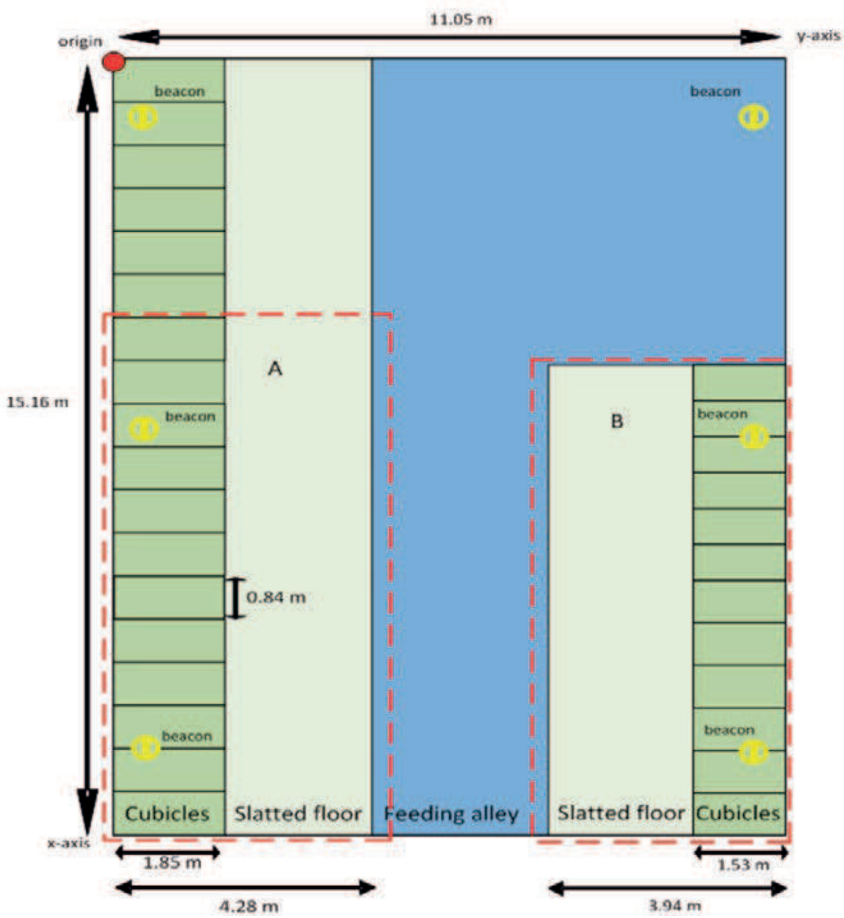


Figure 1. Lay of barn with positioning system.

In the experiments measurements were done with the positioning system, which measured the signal strength of each beacon on all label locations. The labels were placed on 60 different locations, which were equally divided over section B. The positions were divided into five rows parallel to the x-axis and into twelve columns parallel to the y-axis. The rows were placed 1.0 m apart from each other and the columns were placed 0.75 m apart from each other. The real positions, x- and y-coordinates relative to the origin (red dot in Figure 1), were used as the golden standard. At all locations the signal strength of each beacon was measured by a label once every second. Each label sent this signal strength information to the processing unit for calculating the position. During a period of about 50 seconds measurements from the labels were collected and analysed by the processing unit, resulting in calculated label positions expressed as x- and y-coordinates relative to the origin. Because the precision, defined as the difference between the coordinates of a position measurement (each second) and the average coordinates of 30 measurements on a certain label location, showed to be rather high, it was chosen to use the average value of 30 measurements for each label position in the further analyses.

Effects of the configuration of the positioning system, barn construction and equipment on the accuracy were tested. The basic configuration of the positioning system had 6 beacons (Figure 1) and a maximum calibration density of about 1 calibration point per 2.5 $m^2$. First the signal strengths of six beacons and the maximum calibration was used to determine the positions. With the option “simulations” it was possible to use the collected signal strengths data again and calculate the positions with another number of beacons or another number of calibration points. A first simulation was made with only the 4 beacons in the corners of the barn and the maximum calibration density; so in this simulation the signal strength measurements from the two beacons in the middle of the long side of the barn were disregarded. The effect of the number of beacons was tested by comparing 4 and 6 beacons with maximum calibration points. The next two simulations were made with halving the number of calibration points into one per 5 $m^2$ and with the minimum number of calibration points. The minimum number of calibration points was 10 and included the calibration points under each beacon (6) and in each corner of the barn (4). The effects of the barn construction and equipment were tested by analysing the differences in accuracy between the 5 rows and between the 12 columns in which the labels were placed in the test area. These rows and columns had different positions relative to the walls of the barn and the cubicles and the feeding fence in the test area. Finally the effect of two heights of the labels (0.30 m and 0.60 m) was tested with the basic configuration of the positioning system. These heights were chosen, because 0.60 m was by approximation the height of the label when a calf was standing and 0.30 m was the height of the label when lying.

Data from the static experiment was used to determine the accuracy expressed as differences in the x- and y- coordinates and the absolute distance between the real coordinates/positions and the coordinates/positions determined by the positioning system. For the differences in the x- and y-coordinates the values determined by the positioning system were subtracted from the values of the real positions. The effects of the configuration of the system (comparison of 4 and 6 beacons and comparison of minimum, medium and maximum calibration density), barn construction and equipment (comparison of rows 1 to 5 and columns 1 to 12) and height of the labels (height: 0.30 vs. 0.60 cm) were analysed using analysis of variance (ANOVA).

The positioning system and animal behaviour information

Ten 3-4 month old calves carrying a neck collar with label of the positioning system were kept in a part of a pen of the barn (Figure 1: section A within the left red dashed rectangle) consisting of 12 cubicles for lying, a walking area with slatted floor and a feeding fence. For each calf position measurements were recorded per second from March 22 till April 17, 2013. The ration fed at the feeding fence was changed during the registration period; till April 7 the calves were fed ad lib with concentrates and dried alfalfa and from April 8 the amount of concentrate was restricted and pre-wilted silage was fed ad lib. On April 4 and 10 the behaviour of the calves was visually recorded each 5$^{th}$ minute during at least 24 hours. Behaviour was classified as lying or standing in cubicle, standing on slatted floor or standing at feeding fence. In a REML-procedure the effect of the behaviour classes 'in cubicle', 'on slatted floor' and 'at feeding fence' on the y-coordinates generated by the positioning system were tested. Data for the behaviour classes came from the visual observations made each 5$^{th}$ minute. Data from the positing system were transferred to mean coordinates over one minute (~60 measurements) for each label (calf). In the statistical test positioning data from the minutes that correspond with the minutes of the visual observation were used. Results from the statistical analysis were used to set up threshold values for the y-coordinates in order to discriminate between 'in cubicle' or 'on slatted floor' and between 'on slatted floor' or 'at feeding fence'. Based on these threshold values the staying location ('in cubicle', 'on slatted floor' or 'at feeding fence') of each calf in each minute was established. The accuracy (proportion of true results in the population) of in this way established behaviours was calculated by comparing with the observed behaviours (as Gold standard). The accuracy is in this context defined as the number of the true positives plus the number of true negatives as a percentage of the total number of observations. The threshold values were also used to estimate for each day and each calf the time spent 'in cubicle', 'on slatted floor' or 'at feeding fence', providing insight into the day-to-day variation of these behaviours.

## Results and discussion

Static accuracy tests

For the validation tests 120 position measurements (60 label positions in 5 rows, 12 columns and at 2 heights) were made with the positioning system and compared with the real positions of the labels. In Figure 2 the 60 real locations of the labels in the test section of the barn are given as blue bullets on the crossings of the vertical (=columns) and horizontal (=rows) gridlines. The positions estimated by the positioning system are shown as red triangles.

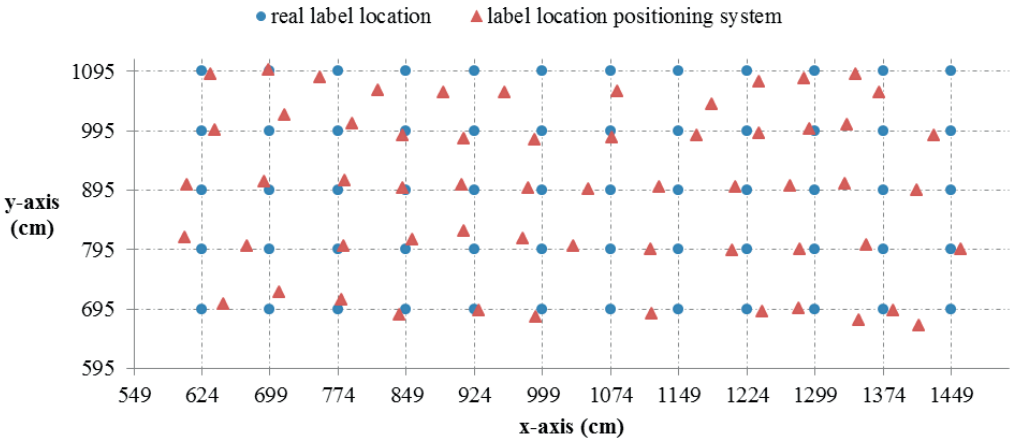


Figure 2. Overview of the real label locations (red bullets) and the locations estimated by the positioning system (red triangles). The system configuration consisted of 6 beacons and had maximum calibration.

For the situation with 6 beacons and maximum calibration the mean accuracy and standard deviation were -6 cm and 34 cm respectively for the x-coordinates and -2 and 19 cm respectively for the y-coordinates. The absolute distance between the real positions and the positions estimated by the positioning system was in average 30.5 cm with a standard deviation of 25 cm. Our results are comparable with the results of Gygax *et al.* (2007), who validated a system developed by Abatec.

The absolute distance in rows 1 and 5 significantly ($p<0.05$) differed from the other rows. The x-coordinates had the largest deviations in columns 8, 11 and 12; the y-coordinates in columns 2, 8 and 12. The resulting absolute distances showed the largest deviations in columns 8, 11 and 12. In general, worst accuracies were found in row 1 and in columns 11 and 12. On these locations the labels were closest to metal sheet pile profile walls and an aluminium roller door; obviously these affected the accuracy. Row 5, that was close to the feeding fence had a significant lower accuracy too. This might be explained by the iron construction of this fence. Gygax *et al.* (2007) also found that the accuracy of the Abatec positioning system depended on the position in the barn.

The height of the labels above the floor (30 vs. 60 cm) only had a significant effect on the accuracy of the x-coordinate; the predicted means for the accuracy of y-coordinate and absolute distance were not affected by height.

The effects of the configuration of the positioning system were tested with simulations.

In Table 1 the effects of decreasing the number of beacons of the positioning system from 6 to 4 on the accuracy is given.

Table 1. Predicted means (cm) of the accuracy with 4 vs. 6 beacons and maximum calibration density.

| Accuracy | 6 beacons | 4 beacons |
|---|---|---|
| x-coordinate | -5.7[a] | 6.3[b] |
| y-coordinate | -2.1 | -3.5 |
| Absolute distance | 30.5[a] | 46.5[b] |

[ab] different letters in the same row mean a significant difference ($p < 0.05$)

The number of beacons had significant effects on the accuracy of the x-coordinate and on the absolute distance. The accuracy of the absolute distance was significantly worse with 4 beacons. Table 2 shows the effect of different calibration densities on the accuracy when used in combination with 6 beacons.

Table 2. Predicted means (cm) of the accuracy with minimum, half and maximum calibration densities and 6 beacons.

| Accuracy | Maximum calibration | Medium calibration | Minimum calibration |
|---|---|---|---|
| x-coordinate | -5.7[a] | -2.9[a] | -29.1[b] |
| y-coordinate | -2.1[a] | -1.4[a] | 24.8[b] |
| Absolute distance | 30.5[a] | 31.6[a] | 84.0[b] |

[ab] different letters in the same row mean a significant difference ($p < 0.05$)

From Table 2 can be concluded that taking away half of the maximum calibration points had no significant effect on the accuracies. The accuracies of a situation with minimal calibration significantly differed from the accuracies of the other two situations.

<u>Animal behaviour information</u>

On April 4 and 10 the behaviour of 10 calves was visually scanned each 5$^{th}$ minute. From these observations the mean daily time budget for lying and standing in cubicles, standing on slatted floor and standing at feeding fence were determined. Between April 4 and 10 there was a strong increase from 11 into 20% of the time for standing at the feeding fence. This was caused by a drastic change in the ration fed to the calves. The calves spent a large part of the day in the cubicles, on April 4 76% and on April 10 66%. Cubicle occupation decreased because more time was spent at the feeding fence.

The effect of the behaviour classes ‘in cubicle’, ‘on slatted floor’ and ‘at feeding fence’ on the y-coordinates generated by the positioning system tested with a REML-procedure are given in Table 3.

Table 3. Predicted means of y-coordinates from the positioning system at different behaviour classes.

| Behaviour class | Predicted means for y-coordinates (cm) |
|---|---|
| Lying in cubicle | 55.0[a] |
| Standing in cubicle | 134.5[b] |
| Standing on slatted floor | 303.9[c] |
| Standing at feeding fence | 395.4[d] |

[abcd] different letters mean a significant difference ($p < 0.001$)

Results from the statistical analysis showed highly significant differences between the y-coordinates of the facilities belonging to the classified behaviours. When lying in a cubicle the label at the neck collar was in average 55 cm from the wall being the origin of the y-coordinate. When standing in a cubicle the calves often were only with the head and the front legs in the cubicle resulting in a larger distance (134.5 cm) from the wall. The predicted mean for standing at the feeding fence was 395.4 cm, while the distance of feeding fence from the wall was 428 cm. This means that when eating the calves often had only their head through the feeding fence, while the neck collar with label was still in the slatted floor area.

Based on the results in Table 3 the threshold values for the y-coordinates in order to discriminate between ‘in cubicle’ (lying as well as standing) or ‘on slatted floor’ and between ‘on slatted floor’ or ‘at feeding fence’ were set at 180 and 380 cm, respectively. With these thresholds the total time per calf per day spent per staying location (‘in cubicle’, ‘on slatted floor’ or ‘at feeding fence’) were compared with the visual observations on April 4 and 10. The accuracies of the in this way established behaviours were 95.1% for ‘staying in cubicle’, 91.9% for ‘staying at feeding fence’ and 88.5% for ‘staying at slatted floor’.

The calculated time budgets on April 4 for ‘staying in cubicle’ and for standing ‘at feeding fence’ were 74 and 10% respectively, compared with 76 and 11% recorded in the visual observations. On April 10 the calculated time budgets for ‘staying in cubicle’ and for standing ‘at feeding fence’ were with 66 and 20% respectively, exactly the same as recorded in the visual observations. The calculated time budgets during the experiment are given in Figure 3.

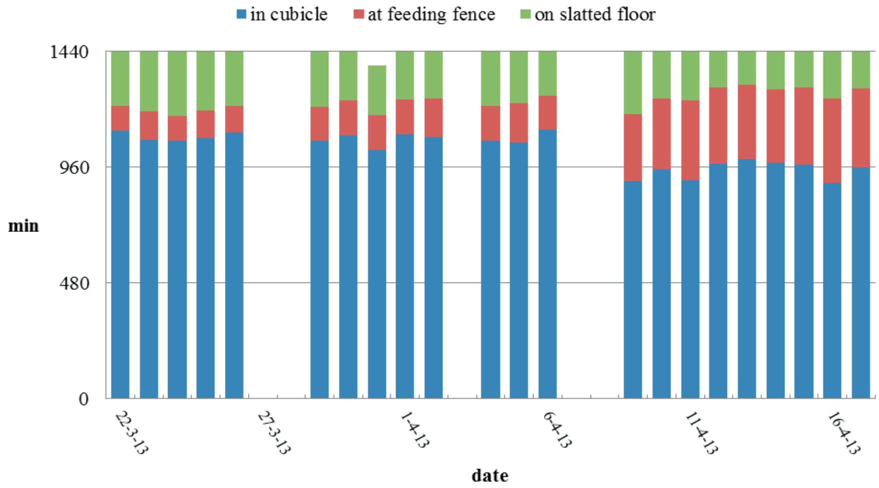


Figure 3. Mean staying time in minutes per calf per day* in cubicle, at feeding fence and on slatted floor during the experimental period.

* 5 days are left out because during parts of these days position registrations were missing.

This graph clearly shows the effect of changing the feed ration on April 8; time spent on feeding increases largely from this date mainly at the expense of time for lying.

## Conclusions

In the basic configuration with 6 beacons and maximum number of calibration points the mean accuracy and standard deviation were -6 cm and 34 cm respectively for the x-coordinates and -2 cm and 19 cm respectively for the y-coordinates. In general, worst accuracies were found when labels were located in the proximity of iron obstacles (walls constructed from metal sheet pile profiles or feeding fence). The overall mean accuracy of the system was 30.5 cm with a standard deviation of 25 cm.
The effects of the configuration of the positioning system, tested with simulations, showed that taking away half of the maximum calibration points had no significant effect on the accuracies.
For the use of facilities determined on the basis of the information from the positioning good accuracies were obtained, ranging from 95.1% for ‘staying in cubicle’, 91.9% for ‘staying at feeding fence’ and 88.5% for ‘staying at slatted floor’.
A change in feeding management (drastic change in the ration composition) was clearly visible in the behavioural information derived from the positioning system. This indicates that the system has potential for online monitoring of animal behaviour for management purposes.

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## References

Gygax, L., G. Neisen and H. Bollhalder (2007). Accuracy and validation of a radar-based automatic local position measurement system for tracking dairy cows in free-stall barns. Computers and Electronics in Agriculture 56(1): 23-33.

Huhtala, A., K. Suhonen, P. Mäkelä, M. Hakojärvi and J. Ahokas (2007). Evaluation of Instrumentation for Cow Positioning and Tracking Indoors. Biosystems Engineering 96(3): 399-405.

WUR (2011). Smart Dairy Farming. Retrieved 19-2-2013, 2013, from http://www.wageningenur.nl/nl/show/Smart-Dairy-Farming.htm.