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Assessing Cows' Welfare: weighing the Cow in a Milking Robot

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Four strain gauge balances were installed into a milking robot after careful inspection of the positions of the legs of all 40 cows from a herd. It was found that 90% of the cows would have all the legs on the balances at least during every second milking. The balances were connected to a four channel amplifier and the data were targeted to a personal computer using a dedicated computer program. From the data, the dynamic weight or load of each leg can be measured. The average weight, the weight variation of each leg, the total weight, the number of kicks, the frequency of kicks and the total time in the milking robot were calculated. The changes in values of each cow were followed and the leg health of cows was observed. Preliminary analysis of the data gives evidence that limb and hoof disorders can be detected with the system. It is also possible to analyse the step and kick behaviour of the cow during milking and during the different stages of milking, washing, milking and disconnecting. In this way it is also possible to monitor the activity level of the cow and how it changes.

1. Introduction

There is a worldwide movement towards automation in cattle husbandry, with the objective of fully automating every process from feeding to milking. Automatic milking has become a common practice in dairy production and, at the end of the year 2003, about 2200 farms worldwide used a milking robot (de Koning & Rodenburg, 2004). Milking robots offer a unique possibility for the dynamic measurement of body weight. It is highly probable that hoof problems, for example, can easily be noted by separately measuring the load on each leg.

Lameness is prevalent in modern dairy herds, causing pain for the cows and economic losses for farms because of loss of production and weakened body condition (Vermunt, 2004). According to a study conducted by Green *et al*. (2002), a decrease in milk yield occurred from 4 months before to 5 months after the cow was diagnosed clinically lame. In their study, the average loss of milk yield because of clinical lameness over 305-day lactation was 360 kg. The loss of production and the effect of lameness on a cow's welfare can be minimised if lameness is detected at an early stage and treatment is started as soon as possible (Guard, 2004).

According to Rajkondawar *et al*. (2002a), lameness is the third most costly problem for dairy herds and the incident rate in United States is 15% of the adult dairy cows. They used two parallel force–plates to measure the forces of cows when they walked over the plates. They concluded that the system could recognise lame animals and identify the affected limbs. They did not measure animals over time, so it was not possible to judge early detection of lameness.

Rajkondawar *et al*. (2002b) also developed a mathematical scoring system for lameness based on their force–plate system. They state that with more data the system would have the ability to detect lameness in individual limbs.

Cveticanin (2003) addressed the problem of livestock weighing with one scaling plate. He introduced fuzzy logic to take care of crowding with good results and achieved accuracy with an average error of 1·5% in the case of single crossing and 2% for the crowded case.

The step and kick behaviour of a cow can also be used when studying animal welfare. Rousing *et al*. (2004) found that higher kick frequency during milking may be the result of pain or discomfort caused by, for example, teat lesions. However, they did not find any relation between lameness and increased stepping or kicking during milking. They suggest that step and kick behaviour measurement might be a good tool for monitoring welfare problems such as udder health and milking techniques. According to Wenzel *et al*. (2003), increased step frequency during milking correlates with increased heart rate and milk cortisol concentration.

Ordolff (1991) studied the behaviour of cows during automatic milking in 1989. He measured the change of weight on the hind legs and the eating behaviour during simulated automatic milking. The cow was standing in a stall with concentrate feeder and scale plates under its hind legs. A phantom robot and a system for simulating the teat cup attachment and teat cleaning were used to disturb the cow at the beginning and at the end of a 6 min measurement. The cow was fed with concentrates during the measurements. The disturbances increased the frequency of cows shifting the weight from one leg to another and it also resulted in higher kick frequency. Disturbance, which lasted 60 s continuously, did not cause changes in eating behaviour (Ordolff, 1991).

An automatic cow health monitoring system was set up at Silsoe, UK. Mottram (2000) studied clinical and sub-clinical ketosis by four automatic methods: breath sampling, individual risk factor analysis using existing herd management records, time series analysis of daily milk yields and measurement of ketones and urea in milk combined with fuzzy logic to simulate human expertise.

The objective of this study was to establish an automatic measurement system of dynamic load on each leg. It was carried out in a milking robot. This paper considers the engineering aspects of the project. Details of the data manipulation and cow welfare analysis will be reported separately.

2. Bovine stability

Figure 1 shows the centre of gravity of a cow and the four hooves on which the cow is standing. Normally more weight is on the front legs and the centre of gravity is nearer the front legs than the hind legs. When lines are drawn from one hoof to another, the stability parallelogram is obtained. As long as the centre of gravity is inside this, the cow has good stability and balance.

When the cow lifts one leg, the parallelogram changes into a triangle [*Figs 1*(*b*) *and 1*(*c*)]. When the centre of gravity is inside the triangle, the cow is still balanced. This is shown in *Fig. 1*(*b*), when the cow kicks with her rear left leg. If the centre of gravity is outside the triangle, the cow has to find a new balance by moving the legs or leaning sideways, otherwise she would collapse. When the cow kicks with the front left leg as shown in *Fig. 1*, the centre of gravity is outside the triangle and the cow has a balance problem. This shows that it is much more difficult to kick with the front legs than with the hind legs, because the centre of gravity is near the front legs (more weight is on the front legs).

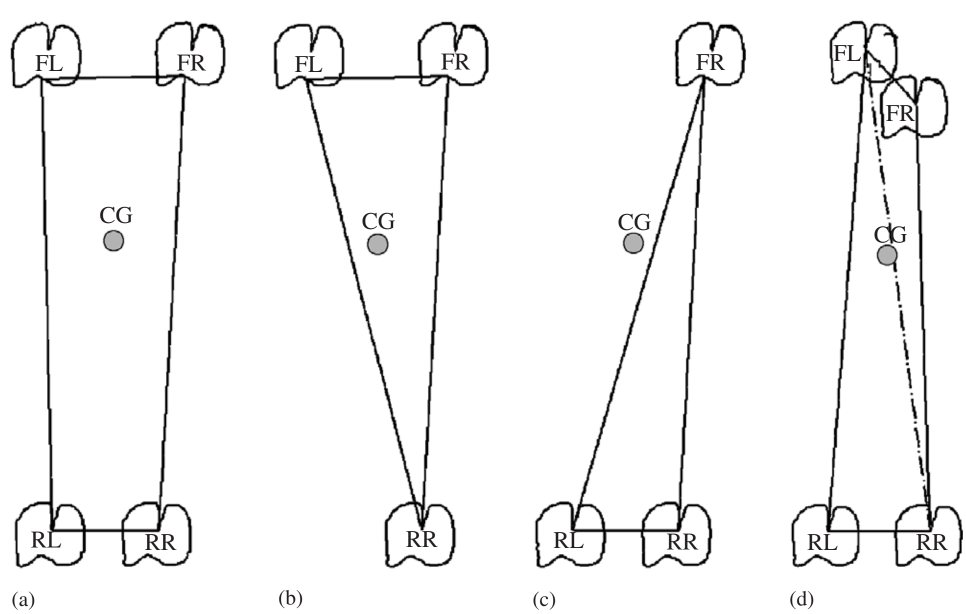

Fig 1. Stability of a cow. CG, centre of gravity; RL, rear left hoof; RR, rear right hoof; FL, front left hoof; FR, front right hoof. (a) Standing on four legs; (b) rear left leg up; (c) front left leg up; (d) front legs close to each other

If the cow keeps the hind or front legs close together as in case *Fig. 1(d)*, it is easier to maintain balance during kicking because there is not much difference between the stability parallelogram and triangle, and the centre of gravity remains inside them if she is standing on four or three legs.

3. Measurements

Four strain gauge balances (1510, Vishay Tedea-Huntleigh, Chatsworth, CA, USA) were installed into a milking robot after careful inspection of the positions of the legs of all cows from a herd consisting of 40 cows (*Fig. 2*). It was found that 90% of the cows have the legs situated so that all the legs would be on the scales at least every second time when the dimensions of the balances were in the range of 300 mm by 400 mm. The size of the balances in the final installation varied from 445 mm by 390 mm to 310 mm by 310 mm depending on location.

The balances were connected to a four channel amplifier (Spider8, HBM, Marlborough, USA) and the data were transferred to a personal computer (PC). The distance between the balances and the amplifier was 40 m. Inspite of this, the system worked reliably and the level of noise remained reasonable. The Internet was used for remote controlling the system and tracking of the measurements. Four web cameras were also installed and the milking was recorded and stored digitally on the PC. Abnormal behaviour could be seen afterwards from the digital video data.

Large amounts of data, 30 Mbytes/day, were accumulated as the measuring frequency had to be set at 10 Hz, in order to see the kicks properly. The duration of a kick can be as short as 0·5 s. More than 100 milkings were recorded in a day. In addition the web cameras generated 17 Gbytes/day of data.

The measuring software was made with TestPoint (Capital Equipment, Bedford, USA). The leg weights were recorded during milking. Information about the cow in the robot and the actions of the robot was automatically taken from the log file created by the milking robot. After each weighing, the data were analysed and the mean leg weights and the number of kicks recorded. The mean values were then compared with those previously obtained from the cow in order to find changes in the weight distribution. During the washing of the robot, the scales were automatically tared. The data were further analysed using MATLAB (MathWorks, Natick, USA) made software. The mean value, standard deviation, kurtosis and skewness of the weight and the number of kicks were calculated for each leg and the behaviour and changes in the values of each cow were followed. The data were also cleaned from improper weighings, *i.e.* when one of the legs was not on the scale plates. The control that the cow is standing on the scale plates is obtained from calculating the

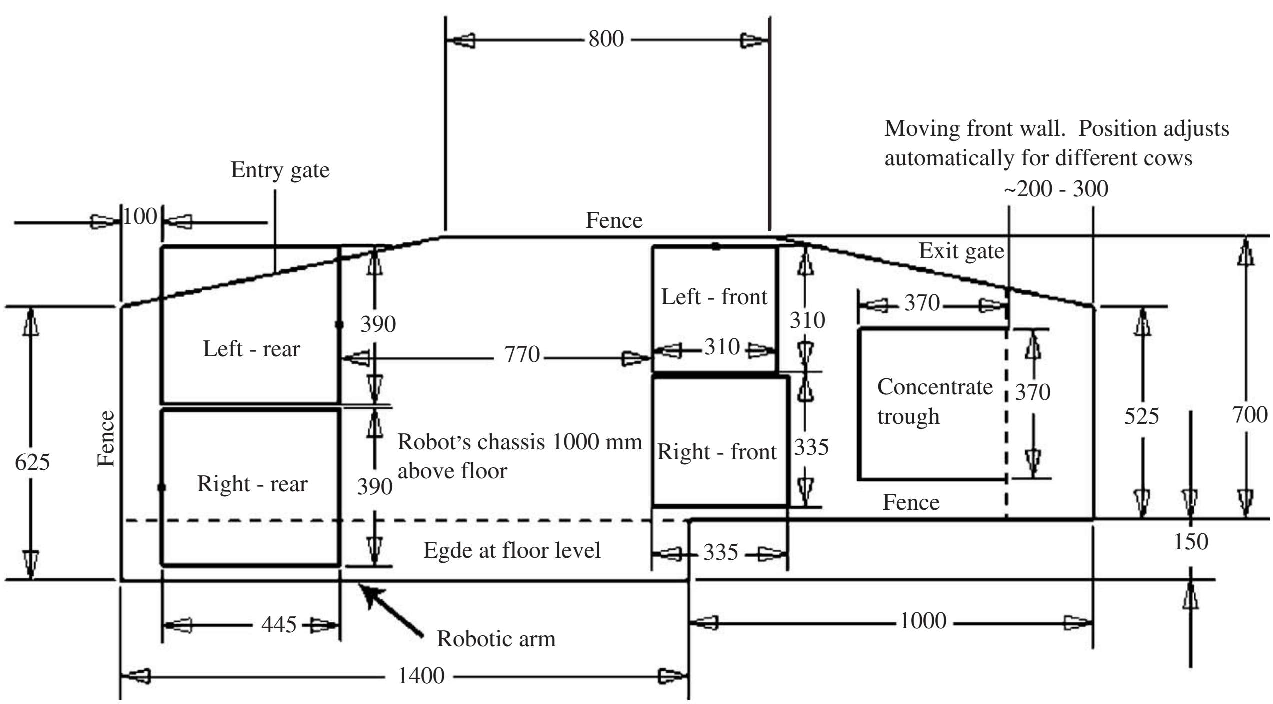

Fig 2. Locations of scale plates and robot's frame

deviation of the total weight from the maximum weight of a cow during milking. Typically over 15 kg deviation means that the cow is not standing properly on the plates.

4. Results

Typical raw data for two cows are given in *Fig. 3*. Occasional peaks can be noticed, which is due to the cow lifting a leg (kicking) or due to weight shuffling (stepping). Every rise on one balance was connected to a decrease on a balance measuring the load on the neighbouring leg. The behaviour can also be seen from *Fig. 3*; the upper figure presents a calm cow and the lower figure presents a restless cow. The sharp changes in the curves indicate kicking during the milking procedure. Kicking can be obtained from curves providing a measure of restlessness. In this study one kick was calculated when the weight of one leg decreased to less than 20 kg. This occurred during kicking as well as when lifting one leg. In the upper

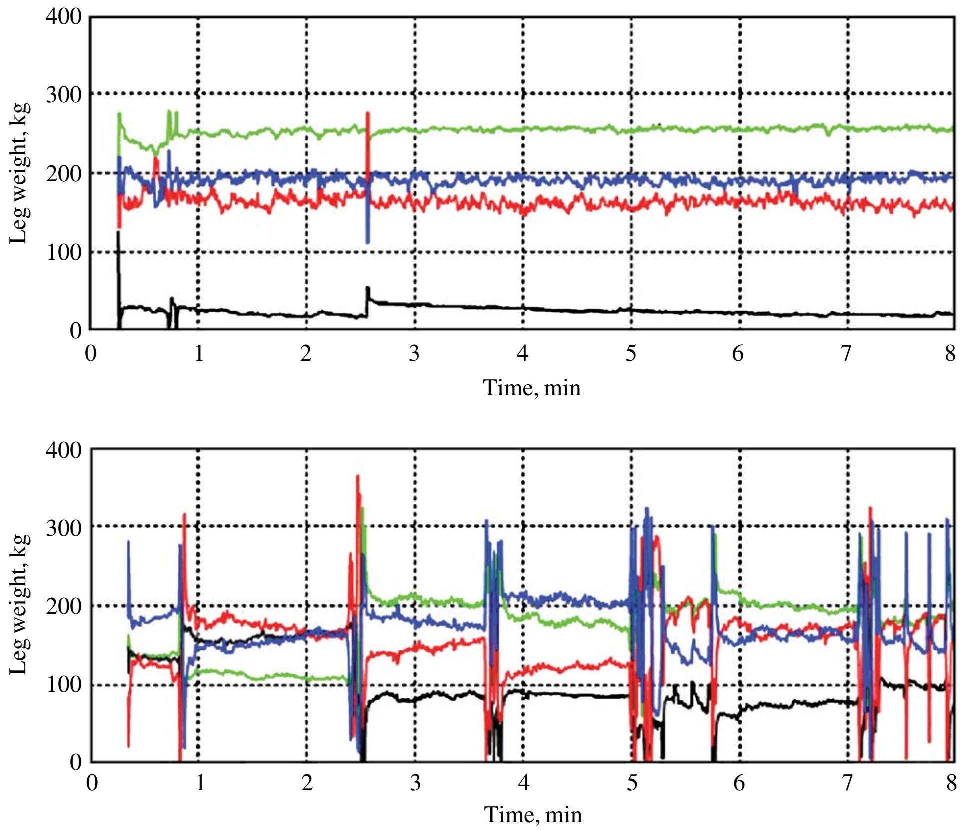

Fig. 3. Test result from two different cow leg loads during milking

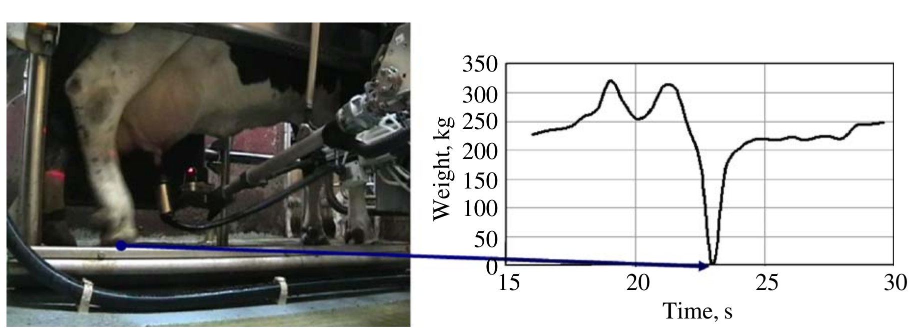

Fig. 4. Weight on right rear leg during kicking

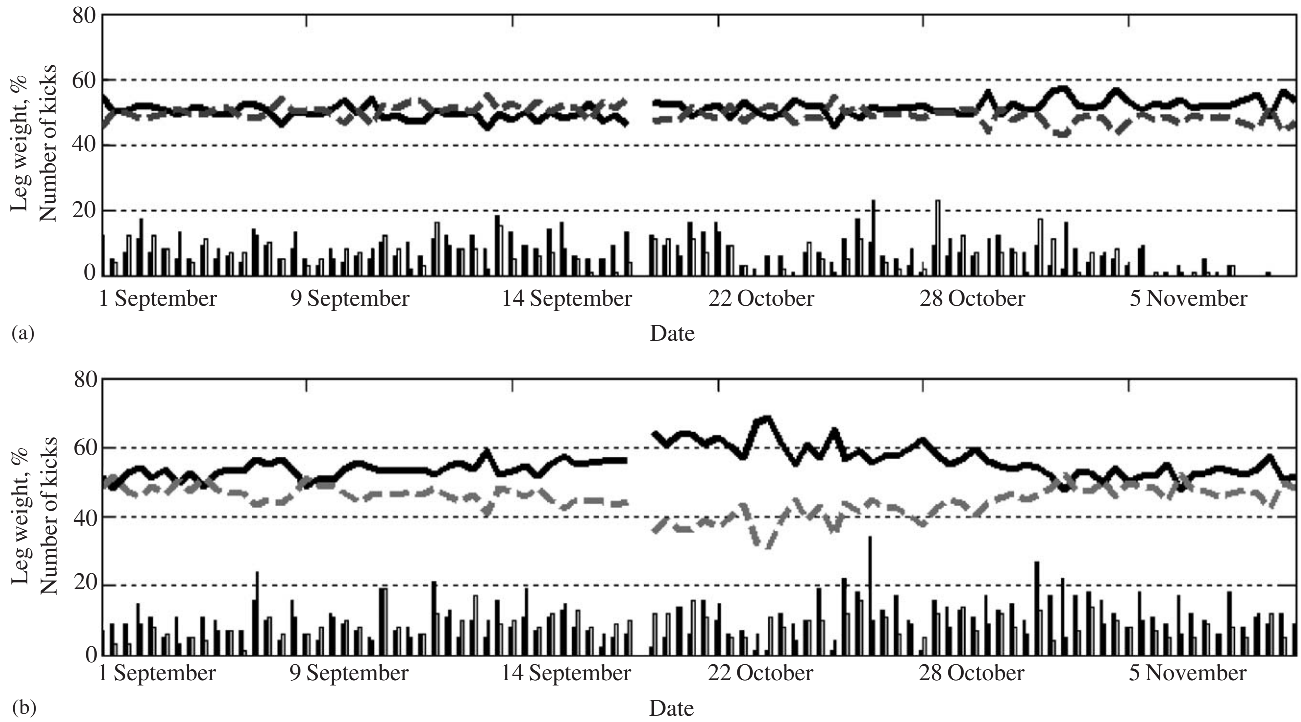

Fig 5. Weight distribution between parallel legs and number of kicks of front (a) and hind (b) legs of cow 289: ——, left leg; – –, right leg; ▬, kicks left leg; ▬ kicks right leg

curve one of the legs was not properly on the scale. In *Fig. 4*, a kick is shown in detail.

Figure 5 shows a long-term follow-up of an individual cow. Cow number 289 was diagnosed as healthy on 1st September and the weight distributed evenly during the period from 18 June to 17 September. Due to problem with the balance, the next recorded data were from 19 October and the cow clearly avoided standing on the right hind leg. A slight tendency to avoid this leg may already be seen during the period from 5 to 17 September. The cow was inspected on 3 November and white line separation with sole off was diagnosed on the lateral hoof of the right hind leg. After hoof trimming and using a block, the weight of the cow has distributed evenly on both hind legs. The cow has also stopped kicking with the front legs.

Changes in behaviour can easily be extracted from the data. For example, the kicking frequency of cow number 181 during 33 milkings is given in *Fig. 6*. The distribution has a normally distributed component as would be expected. On the other hand, there are a few milkings where the kicking frequency is unusually high or low. This reflects changes in the cow's behaviour; increased frequency indicates possible problems in milking.

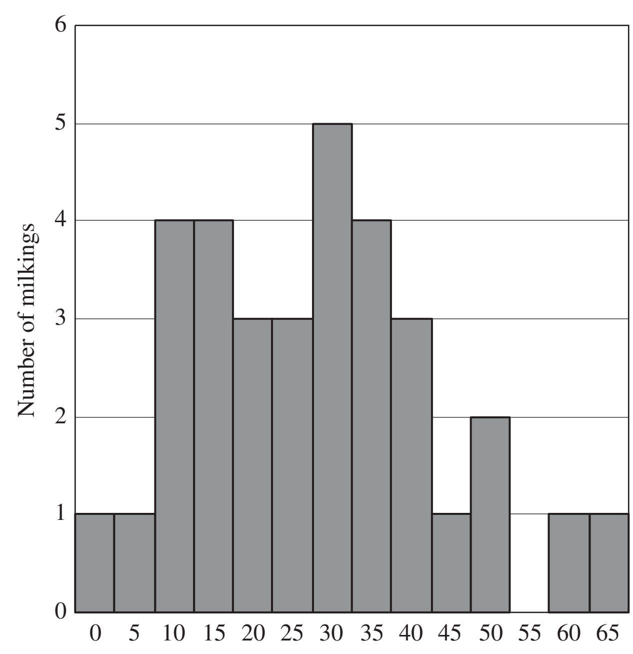

Fig. 6. Kicking frequency of a cow during 33 milkings

The mean weight on each leg of a sick cow, number 181, during 33 milkings is given in *Fig. 7*. The cow had injured its left hind leg and is therefore keeping more weight on the right hind leg. At the same time the cow also has to shift more weight on the right front leg in order to keep its balance.

A very clear change in the behaviour of cow number 570 can be seen in *Fig. 8*. The weight distribution was constant until 25 August. Then the cow avoided putting weight on its left hind leg, and kicking with the left leg increased considerably. The cow was inspected on 1 September and was found to be clinically lame. A strain or a sprain on the left hind leg was diagnosed. The leg healed without treatment and on 15 September the leg weights had almost returned to the level prior to the injury.

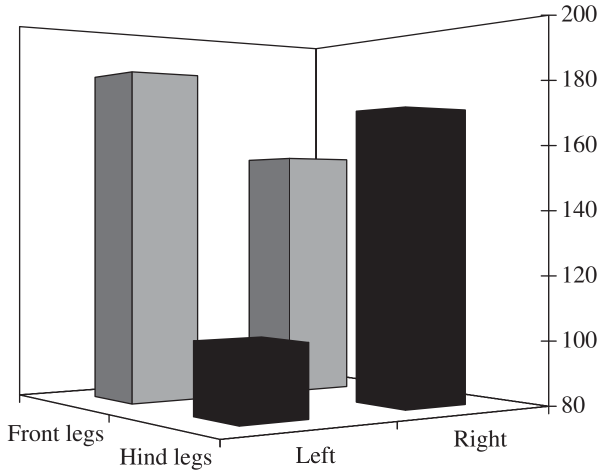

Fig. 7. The mean leg weights (kg) of a sick cow during 33 milkings. The values for front legs, hind legs, left and right are 183·1, 102·1, 157·4, 171·2 respectively

5. Discussion

After experience over 1 yr, it can be concluded that in principle the system functions as expected. However, the balances are on constantly and are subject to severe loads. The fixing of the transducers and platforms has been problematic. This is due to the leg loading, since the transducers were not designed for concentrated point loads but for a larger load area. Not all the measurements are successful. This is due to the different sizes of cows and it was already noticed during the design of the scale plates. Cows can also put their legs outside the platform during milking or they may lean on the robot chassis resulting in lower weights than normal. However, these cases can be detected automatically and these useless data may be cleared.

The system can give reliable information about leg health and step and kick behaviour. The final goal is an automatic alert system. Preliminary analysis of the data

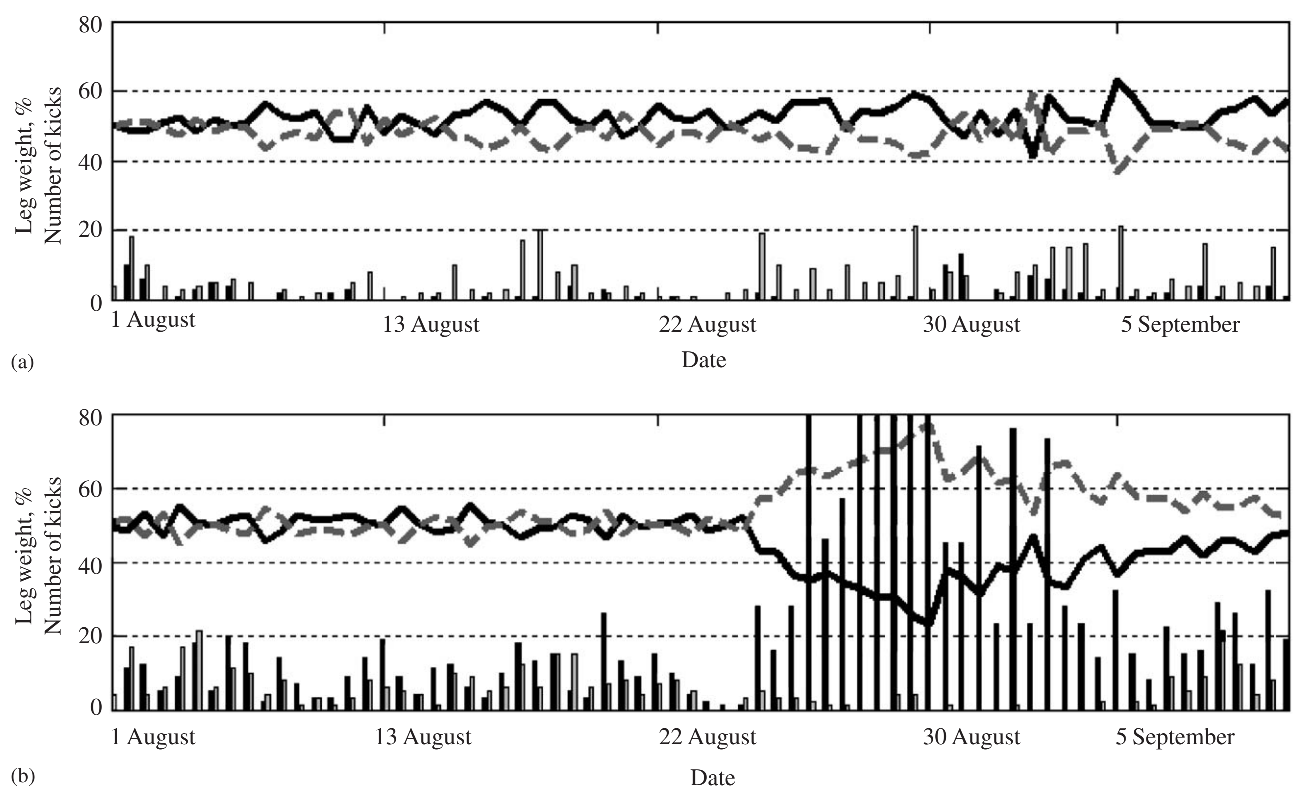

Fig 8. Weight distribution between parallel legs and the number of kicks of front (a) and rear legs (b) of cow 570: —, left leg; – –, right leg; ■, kicks left leg; ■, kicks right leg

gives evidence that limb and hoof disorders can be detected with the system. More research is needed to find out if various diseases can be detected with the system before clinical symptoms or acute lameness appears. It seems that cows and diseases can and must be grouped in various ways in order to make the automatic detecting process function properly. *Figures 5 and 7* give evidence that the leg disorders may be differentiated at least into two groups: hoof problems, where the difference between legs changes more slowly, and injuries, when a sudden difference is noticed. Also increased step and kick frequency seems to be a good indicator of lameness contrary to the findings of Rousing *et al.* (2004). However, long-term follow-up of the cows is needed in order to obtain reliable criteria for the automatic warnings, and further analysis of the data is needed to find out the optimal criteria for lameness. Steps and kicks can be separated from each other for more precise behavioural observation. In some cases skewness and kurtosis have given promising information, and these findings will be reported in the near future.

This system evidently operates only when the cow is in some of the self-service units (concentrate feeder, milking robot, *etc*). Otherwise one must use more sophisticated walkthrough scales (Rajkondawar *et al.*, 2002a). The much shorter detection time presents a problem, and consequently more sophisticated software is needed.

6. Conclusions

The system can be used to detect lameness, and in future the milking robots or feeding systems can be equipped with the automatic weight-measuring system and the alert system to announce diseases in a cow.

The step and kick behaviour of a cow can be seen from the data, *i.e.* a calm cow can be differentiated from a restless cow. The number of kicks and steps can be calculated from curves and a quantitative measure of restlessness can be obtained.

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