Design and implementation of a system for automatic milking and feeding


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Devir, S., Hogeveen, H., Hogewerf, P.H., Ipema, A.H., Ketelaar-de Lauwere, C.C., Rossing, W., Smits, A.C. and Stefanowska, J. 1996. Design and implementation of a system for automatic milking and feeding. Can. Agric. Eng. 38:107-113. To investigate the feasibility of implementing a completely automated milking and feeding under typical dairy farm conditions, a prototype fully integrated system was designed and installed at an experimental farm. The barn had the following sections: a feeding area, a lying area, and an automatic milking system area. The automatic milking system included a milking stall with a robot for automated attachment of the milking cluster and two selection units. Concentrates can be fed in the milking stall as well as in the selection units. Cows enter the automatic milking system from the lying area through one of the two selection units and can be sent to the milking stall or to the feeding area. In the milking stall, cows are milked automatically by the milking robot. In the feeding area, an automated feeding system is available, in which the individual forage intake of cows can be controlled and measured. The process control can be divided into three groups: robot control, cow traffic control, and management control. The system offers much flexibility with regard to the milking frequency, cow traffic, and feed allocation. The system was used for 7 months with a one-way cow routing and an average of 79 planned milkings per day. Many data were collected automatically and could immediately be utilized for on-line decisions. Although many questions still have to be answered, the system proved to be flexible enough to allow automatic milking and feeding with much variation in milking frequency, feedstuff allocation, and cow traffic.

Pour permettre d'automatiser complètement la distribution des aliments et la traite en contexte pratique, un prototype d'un système complètement intégré a été développé et mis en place dans une ferme expérimentale. Dans la conception générale de la stabulation, 3 secteurs sont distingués: une aire d'alimentation, une aire de couchage et une installation de traite automatisée. Cette installation de traite automatisée comporte une stalle avec un robot de traite et deux unités de tri. Les concentrés peuvent être distribués, soit dans la stalle de traite, soit dans les unités de tri. Les vaches entrent dans l'installation de traite automatisée à partir de l'aire de couchage par une des deux unités de tri et là, elles sont envoyées, soit vers la stalle de traite, soit vers l'aire d'alimentation. Dans la stalle de traite, les vaches sont traitées automatiquement par le robot. Au niveau de l'aire d'alimentation, un système de distribution automatisée d'aliments permet de distribuer du fourrage aux animaux en mesurant et maîtrisant les quantités ingérées individuellement. Le contrôle d'ensemble des procédures est divisé en trois groupes: le contrôle du fonctionnement du robot, le contrôle de la circulation des animaux et le contrôle de la conduite d'élevage. Le système a été utilisé pendant une période de sept mois dans une stalle de traite à voie unique avec

en moyenne 79 unités de traite par jour. Un grand nombre de données ont été enregistrées automatiquement ce qui a permis leur emploi immédiat pour des processus de décision informatisés. Bien que certaines questions restent encore à ressoudre, le système a fait preuve d'une flexibilité suffisante pour permettre des opérations automatisées de traite et d'alimentation avec un haut degré de variation dans la fréquence de traite, de distribution des rations et de circulation des animaux.

INTRODUCTION

A large part of the human labour involved in dairy farming is dedicated to milking (Sonck 1993). In an economic evaluation of automatic milking, it was estimated that milking twice a day, including related activities, for 125 dairy cows will take 3.8 man-hours per day in a standard milking parlour system (Harsh et al. 1994). Besides labour costs, the milking routine is becoming more and more socially unacceptable because it requires work at set times, seven days per week. In recent years, milking has become easier because of well designed milking parlours, detachers of milking clusters, and animal identification systems (Dodd and Hall 1992; Rossing and Spahr 1992). The attachment of the milking cluster is the last part of the milking operation that needs to be automated. In recent years, much effort has been devoted to the development of automatic milking systems (AMS), resulting in several existing approaches to complete automation of the milking process (Artmann 1994; Rossing et al. 1994). Some AMS’s are now commercially available and approximately 30 have been sold to Dutch commercial dairy farms.

Automatic milking means more than labour cost savings. By using an AMS, cow management can be performed at the individual cow level (Devir et al. 1993b). Using available on-line data, such as body weight, electrical conductivity of milk, and activity of cows, more insight into the physiological state of a cow can be gained. The milking and feeding regimes can be adjusted based upon daily information on the physiological state of an individual cow (Maltz and Metz 1994). The use of an AMS with individual management requires a cow routing system in which cows enter the AMS with minimum human interference and at a proper frequency. A system for automated milking and feeding demands management of individual cows based upon on-line collected data and requires integration of various components. No descrip-

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tion of such a system could be found.

The objective of the research described in this paper was to design and implement an integrated system for automated milking and feeding. Design criteria were to use as much commercially available products as possible, to use a cubicle house (as is very frequently used in Dutch dairy practise) for the system, to enable automatic feeding and milking of cows, to collect enough data on-line to enable on-line individual cow management as described by Maltz and Metz (1994), and to make the system as flexible as possible.

This paper describes the barn layout, components and process control of the system, as it is implemented at an experimental farm. To demonstrate the use of the system, an experiment with a certain configuration is used and performance figures for this configuration are presented.

**SYSTEM DESCRIPTION**

**Layout of the cow shed**

The AMS cow shed was divided into three parts: feeding area, lying area, and AMS area (Fig. 1). The cows were kept on a slatted floor with a manure scraper. The feeding area was equipped with an automated forage feeding system with 17 forage troughs and 3 drinking troughs. Besides the forage feeding system, there was an automated concentrates dispenser. The lying area had 38 cubicles on both sides of the slatted floor and one drinking trough. Cows could enter the AMS only from the lying area. When leaving the AMS they came into the feeding area. There were two passages between the feeding area and the lying area. The AMS consisted of selection units and a milking stall. Because cows might attempt to visit the AMS very frequently, the number of selection units must be adequate. Therefore, two selection units were created.

**The selection unit**

The two identical selection units consisted of entrance and exit gates, presence sensors, cow identification system, weighing equipment, and a concentrates feeder. When a selection unit was unoccupied, the entrance gate of that selection unit was open. To detect oestrus (Arney et al. 1994; Liu and Spahr 1993), an activity tag including a transponder (Nedap Agri, Hengelo, The Netherlands) was attached to a front leg of each cow. When a cow entered the selection unit she was identified by the transponder and the count of the activity tag was transferred. After identification, the cow could receive concentrates. The amount of concentrates that a cow received was determined by the management system. The floor of the selection unit was mounted upon a commercially available weighing scale (Welvaarts, Den Dungen, The Netherlands). Each time a cow was in the selection unit, her weight was determined. When the cow was in the selection unit, a decision was made whether a cow was ready for milking or not. If a cow was ready for milking, a signal was sent to the milking stall to notify the milking stall which cow was coming next and the exit gate was directed to the milking stall. If a cow was not eligible for milking, the exit gate of the selection unit was directed to the feeding area. Cows reluctant to leave the selection unit were pushed out by a mechanical pusher.

**The milking stall**

A commercial milking stall (Prolion Development, Vijfhuizen, The Netherlands) consisting of a milking system, two milking stalls, and a robot arm equipped with sensors for...
Fig. 2. Layout of the milking stall.

Teat location (Bottema 1992) was used. Each milking stall had a milking cluster containing four teat cups and for each teat cup an attachment mechanism. The robot arm could be used for both milking stalls. For better access to the udder by the robot arm, the front of the milking stall had a 100 mm high platform (Mottram 1992; Mottram et al. 1994). The rear part of the milking stand was equipped with leg spreaders (Fig. 2). Because of the slopes in the legs spreaders, a cow had to spread her legs and stand properly for automatic attachment of the teat cups. When the cow entered a milking stall and was identified by her neck transponder (because of practical reasons each cow had two transponders, one integrated with the activity tag and one around the neck), the movable concentrates trough moved to adjust the length of the milking stall to the length of the cow and the entrance gate closed. Then the robot arm moved under the cow together with the milking cluster. The robot arm contained two ultrasonic sensors for location of the teats. The first sensor (reference sensor) located the right front teat as a reference. The second sensor (fine sensor) moved up and down and had a rotating field. It measured the distances and angles of the reference teat in relation to the other teats (Fig. 3). The teat position information was stored and used to attach the four teat cups. When all the teat cups were attached, the robot arm disconnected and moved back to its rest position. When milk flow fell under 0.2 kg/min, the teat cups were removed. The exit gate then opened and the cow could leave the milking stall. When a cow fell under 0.2 kg/min, the teat cups were removed. The exit gate then opened and the cow could leave the milking stall. When a cow was reluctant to leave, a mechanical pusher pushed the cow outside. When the cow had left the milking stall, the exit gate closed, the feeding trough returned to its starting position, and the entrance gate opened to make the milking stall available for the next cow.

The forage feeding system

Forage could be fed separately. The forage feeding system consisted of 20 feeding gates with cow identification equipment and troughs. Three troughs were designed for water allocation and 17 were designed for forage allocation. Groups of five troughs were positioned above a weighing bar (Ipema and Metz 1992) (Fig. 4). The feeding gates were normally in an upward position so that a cow might insert her head but could not reach the trough. When a cow inserted her head and was identified, the gate moved into a downward position, allowing the cow to eat. A presence sensor mounted in the gate used a light beam. As long as the light beam was interrupted, the cow was allowed to eat or drink. As soon as the light beam was not interrupted, the gate moved to the upward position and the trough was lowered to the weighing bar. When the weight of the trough (including the remaining feed or water) was recorded, the trough was set to its starting position for the next cow to enter. The water troughs were then refilled. At preset times (defined by the management), a forage wagon automatically drove in front of the feeding troughs and filled the feeding troughs to a preselected weight. The forage wagon could contain two different types of forage.

Process control

Presence sensors working by means of light beams were positioned at various places in the AMS and were used for opening and closing of gates. The system for complete automatic milking and feeding was controlled by three computer systems (Fig. 5). All processes in the milking stalls, such as opening and closing of gates, milking, and attachment of milking clusters, were controlled by a VME computer system. The user-interface of the VME system was a PC 386 running under MS-DOS. Data of milk yield and electrical conductivity of the milk were also collected by the VME system. The control of other processes and all other data collection were carried out by a DEC PDP-11 system, which was the computer dedicated for normal process control on the experimental farm. The data collected by the VME and DEC PDP-11 systems such as feed intake, time of entrance and leaving of the feeding gates, the selection units and the milking stalls, milk yield, and electrical conductivity and temperature of the milk, as well as data derived from other sources (i.e., dairy herd information association, breeding organization, veterinarian, etc.) were stored on a DEC VAX computer. A PC was dedicated to make decisions on concentrates and forage allocation, milking frequency, and cow routing. This PC could use data from the DEC VAX computer for its decision making process. Decisions made by the management PC were carried out by the DEC PDP-11.

TEST RESULTS

The system described in this paper was used for 7 consecutive months with 24 cows. The 25 cubicles in the lying area and 12 feeding troughs and 2 water troughs in the feeding area closest to the AMS were available for this group of
Fig. 3. The milking robot.

Fig. 4. The forage feeding system.
cows. One passage between the feeding area and the lying area was closed. A one-way gate was installed in the other passage between the feeding area and the lying area so that cows could not go directly from the lying to the feeding area but had to go through the AMS (one-way cow routing). The AMS was available all day except when the system was being cleaned. Because a small group of cows had to be milked, only one milking stall was used. Forage was available all day ad libitum. The forage wagon refilled the troughs each 30 min. Concentrates were only provided in the selection units and the milking stall. A dairy control and management system (DCMS) was installed on the management PC. The DCMS determined the concentrates allocation and milking frequency, based upon available data on stage of lactation, milk production, body weight, and feed intake of each individual cow. When a cow visited the selection unit, the DCMS decided whether the cow could be sent to the milking stall and the concentrates allocation in the selection unit as well as in the milking stall, based upon the planned milking frequency and the visiting pattern of the cow to the AMS (Devir et al. 1993b).

During the seven month period, an average of 79 milkings per day were planned. The actual average number of milkings per day was 85.4, with an average of 258 visits per day to the selection unit. More than 97% of all milkings were voluntary visits. The two selection units were engaged for more than 70% of the available time, during the most busy hours (1600-2000 h) the selection units were occupied for 74% of the time. A diurnal pattern could be seen in selection unit visits. Each milking took an average of 10.6 min. The milking stall was occupied for 62% of the available time, with a maximum of 63% during the most busy hours (0400-0800 h).

A large amount of data on physiological status of the cow, production, feed intake, and cow traffic could be collected on-line and could be utilized directly by the DCMS on the management PC.

Fig. 5. Control of the system for complete automatic milking and feeding. SU = selection unit, MS = milking stall.

DISCUSSION

System design

For truly automated milking and feeding, cows must visit the AMS and the feeding places without human interference. Therefore, cows must visit the milking stall voluntarily. Former experiences with the use of an AMS (Ketelaar-de Lauwere 1992; Ketelaar-de Lauwere et al. 1993; Ketelaar-de Lauwere and Benders 1994; Metz-Stefanowska et al. 1989, 1993a, 1993b; Winter et al. 1992) were used to define the position of the main areas of the system (lying area, feeding area, and AMS area) for a high rate of voluntary visits. However, when cows must visit the milking stall voluntarily, some cows might not visit the AMS often enough to be milked frequently enough, while other cows might visit the AMS more times than necessary to obtain planned milking frequencies.

It is possible to use the milking stall also for selection. When cows are not due for milking because the time since the last milking is too short, they are sent out of the milking stall immediately. The disadvantage is that the total capacity of the AMS will decrease because of visits of cows to the milking stall without being milked (Devir et al. 1993a). Since the milking stall is the most expensive part of the AMS, unnecessary visits to the MS should be prevented as much as possible. Therefore, the selection unit was developed to select cows due for milking before they entered the milking stand. Cows who are not due for milking are sent back to the herd. Cows who have to be milked are sent to the milking stand. Selection can also be performed by a walk-through selection system (e.g., Carrano 1994). However, this suggests that, when the MS is occupied, cows have to go to a waiting area, which might have consequences for cows with low social ranking. Besides, measurement of the body weight is easier in a selection unit compared to walk-through selection, because cows stand relatively quietly in the selection.
unit for at least some moments (Peiper et al. 1993; Ren et al. 1990). Moreover, problems might occur with the allocation of concentrates, because the cows with a high demand of concentrates have to eat more concentrates in a relatively short time during milking.

To decrease as much as possible the number of cows who are not milked frequently enough, cows must be attracted to the AMS. Offering concentrates in the AMS is one way to attract cows. The comfort of the milking stall is also an important factor in making the cows enter the AMS voluntarily (Hurnik 1994). Also, one-way cow routing can be introduced. In one-way cow routing, cows have to go through the AMS in order to move from the lying area in a barn to the feeding area in the barn. One-way cow traffic might have a negative influence on the welfare of the cows (Ketelaar-de Lauwere 1992). A conclusive answer on the use of one-way cow routing versus completely free cow routing has not yet been given. In general, when cows must visit the AMS voluntarily there always will be some cows that do not come and the herdsman always has to reserve some time per day to guide these cows to the AMS. The percentage of cows who have to be guided to the AMS is a very important figure in the acceptance of automatic milking on commercial dairy farms.

The forage feeding system was designed to be flexible. Because cows have to be identified before they get access to the system, forage can be fed ad libitum as well as restricted. Moreover, because of the weighing, forage intake can be utilized on-line for management purposes. The use of presence sensors in the forage system appeared to be very important to determine whether a cow had left the feeding gate.

The control of the system described in this paper employs several computer systems. The reason for this was the existing infrastructure on the experimental farm on which the system described in this paper was implemented. It is possible to control the described system, except the milking stall equipment, with a PC (with at least a 486 DX processor).

The components of the system for automated milking and feeding are rather innovative, but all of them have already been described and most of them are commercially available. The innovative feature of the system is that it integrates all these components and thus gives the possibility to utilize a large amount of on-line data of individual cow management. Control of concentrate amounts and distribution over the day, as well as milking frequency and disease detection might be carried out automatically in the future. To be able to utilize the data fully, much effort has to be put into the development of management and control systems, such as the DCMS.

Most of the design criteria which were defined were satisfied. The feeding system, which was already developed and installed on the experimental farm (Ipema and Metz 1992), is probably too expensive to use on commercial dairy farms. The software to integrate the various components of the system had to be developed and the results showed that automatic milking and feeding were possible with the system. The use of the DCMS during the test proved that enough data could be collected to make on-line decision making possible. Although the flexibility was difficult to obtain, for management purposes the system is flexible enough. To change individual cow management only the software has to be adjusted.

Test results
The objective of this paper was to give an indication of the performance of an integrated system for automatic milking and feeding of dairy cows. The DCMS could very well perform with the available data which shows that it is possible to utilize on-line data from various sources in individual cow management.

The results indicate that, at least in a one-way cow traffic situation with concentrate allocation in the AMS and a group of 24 cows, a high voluntary visit rate is possible. The measured voluntary visit rate of 97% means that with a planned milking frequency of 3 times a day, 2 cows had to be brought to the AMS each day. It is difficult to extrapolate these figures to larger group sizes because the test was carried out with a relatively small group and an overcapacity; during busy hours, the milking stall was used 63% of the time. The selection units were used for 74% of the time during busy hours. When larger groups have to be milked automatically, the number of selection units necessary might become a problem.

CONCLUSIONS
A system for automatic milking and feeding has been designed and described. The flexibility of the system for automatic milking and feeding as described in this paper allows much variation of milking frequency, concentrates, and forage allocation and cow traffic. Moreover, automatically collected data can be utilized for management of individual cows. Initial results show that automated milking and feeding including individual cow management are very possible using the system described.

Much research still has to be carried out to determine optimal cow husbandry in an automatic milking situation and to develop systems to fully utilize the available data. The system described in this paper should be of great use for this type of research.

ACKNOWLEDGEMENT
The authors gratefully acknowledge R. Bijkerk, F.H. Ettema, T. Janssen, and H.J.J. Janssen for their work in implementing the system for complete integrated automatic milking and feeding. Dr. J.H.M. Metz is acknowledged for his useful comments on earlier drafts of this paper.

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