# The Role of the Cow in Automatic Teat Cup Attachment

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## ABSTRACT

A system for automatically locating the teats of a cow and attaching teat cups was developed and used to milk nine cows for 10 consecutive d. For the first 5 d, the cows were milked three times a day at fixed intervals of 12, 6, and 6 h. For the subsequent 5 d, cows were intercepted for milking on their way from a bedded area to a forage feeding area; the mean numbers of attendances per cow were 3.2/d (range 2 to 4). Of 279 cow visits for milking, 72% were successful. Of the 77 occasions on which all four teat cups were not attached, 13 were attributable to the response of the cow (for example, kicking the robot); 46 were due to a difference between the estimated teat position and the actual teat position; and 14 were due to operational failures of the equipment. Eighty-five percent of attempts to attach individual teat cups were successful. Of the 162 failed attempts to attach teat cups, 15% were due to cow response, 54% to positional error, and 21% to engineering malfunctions. In treatment 2, cows that stayed in the stall for more than 5 min after milking were prompted to leave, which occurred during 13 (9%) visits. Cow behavior did not appear to be a major obstacle to the unsupervised use of automatic milking.
(**Key words**: milking, automation, animal behavior, cows)

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## INTRODUCTION

Automatic milking systems to carry out milking parlor operations without routine human attendance have been under development for some years (8). Frequent milking may have beneficial effects on yield (4), susceptibility to mastitis (5), and feeding efficiency (17) and may require changes in many other aspects of husbandry, such as building design (2) and fertility management (9). Automatic milking may reduce the cost and rigor of routine tasks, particularly for frequent milkings, and might also improve the welfare of cows in that they could be milked ad libitum, possibly more frequently than twice a day (13). In the United Kingdom, recruitment and retention of skilled staff are becoming more difficult (7).

The aim of automatic milking is the successful removal of milk from a cow without routine human attendance. This work attempted to identify those aspects of cow behavior that have a direct impact on the operation of a robot for teat cup attachment.

An automatic milking system is not successful if the cow does not actively respond in key events. She must come to the entrance of the milking parlor, whether voluntarily or under some compulsion. She must voluntarily enter the parlor or stall, stand in a position that does not obstruct the robot (11), and then leave the stall after milking.

Successful teat cup attachment has been reported by several teams (8), although the criteria for success differ. For example, Hogewerf et al. (6) defined only attachments of all four teat cups as successful but allowed several attempts, each starting from the "at rest" position of the robot; up to 14 attempts were reported for one cow at a single milking.

By contrast, Frost et al. (3), in a previous experiment with the Silsoe Research Institute automatic milking system, allowed only one attempt to attach all four teat cups from the "at

TABLE 1. Percentage[1] of successful and failed teat cup attachment attempts from an at rest position (1).

| Attachment | (%) |
|---|---|
| Success | 84 |
| Failure | |
| Operational | 6 |
| Conceptual | 2 |
| Positional | 8 |

[1]Of 1440 attempts.

rest" position. The results of each attempt at teat cup attachment were classified into four groups (Table 1). The causes of positional failure were not clear; they may have been due to cow posture (a conceptual failure) or software error (an operational failure). In the previous trial (3), failures to attach teat cups that were due to an inadequate response from the cow, for example, by failing to get onto the step, were not included as valid attempts to attach teat cups, and data were not recorded.

In the present study, the definition of conceptual failure was extended to include the effects of the behavior of the cow in reducing the success of teat cup attachment via four main causes, attendance at the stall, entry into the stall, posture in stall, and exit from the stall.

## MATERIALS AND METHODS

The automatic milking system (15) comprised a stall to hold and identify the cow, a gate to control access to the milking stall, a holding point for teat preparation, a milking stall, a robot arm to attach teat cups, a milking system with four separate teat cups, and an exit passage with teat sprayer (Figure 1). One-way spring gates controlled the direction of circulation of the cows through the system (Figure 1).

At each milking, the cow entered the identification stall where she was separated from the herd and was identified by means of a radio transponder. Cows could be diverted from entering the milking stall by closing gate C (Figure 1). Once a cow was accepted for milking, sliding door D opened to reveal the milking parlor. When the cow approached gate E, door D was closed, and the teats were either

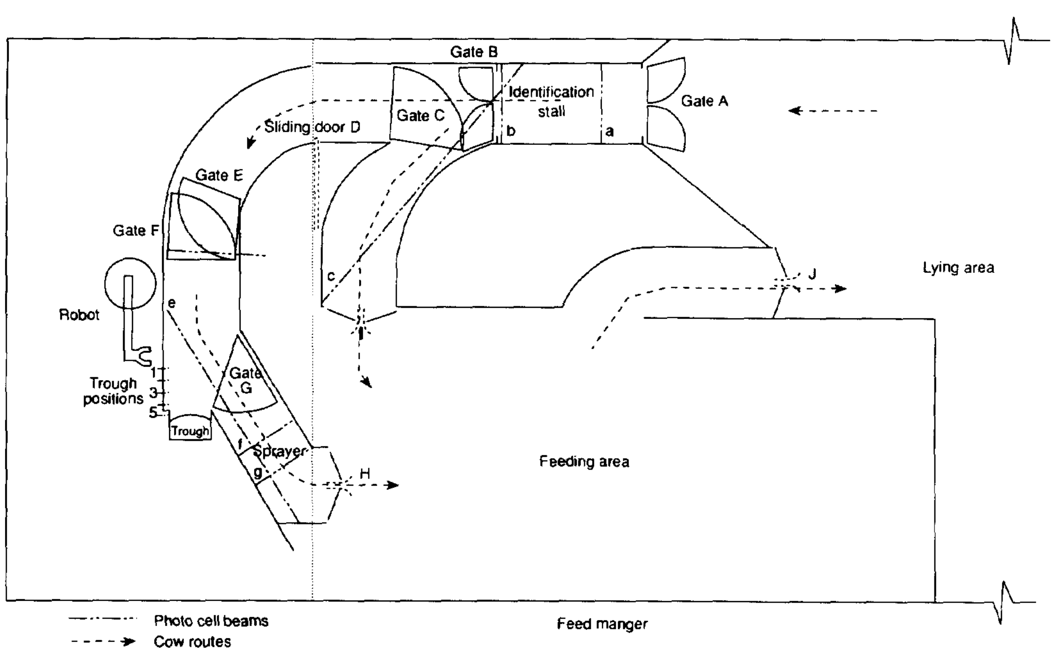


Figure 1. Layout of the Silsoe Research Institute automatic milking system.

cleaned manually by wiping with a moist sanitized disposable towel or, if heavily soiled, were hosed, stimulating the milk letdown response. After teat preparation, gates E and F were opened, and the remainder of the sequence was entirely automatic.

As the cow entered the stall, breaking beam d, the feed trough, starting from position 1, moved forward to one of five predetermined positions, depending on the size of cow, and a small amount of feed was dispensed. The movement of the trough was important; it drew the cow forward to place her front feet onto a 200-mm high step, thereby improving access to the teats (11). Once beam d was clear and beam e was broken, the rear gate was closed. A continuous trickle of feed was dispensed for 2 min after the cow entered the stall. A total of 250 g of cubed 16% protein dairy concentrate feed was dispensed at each milking.

The robot arm then picked up and attached teat cups in the sequence rear left, rear right, front left, and front right. The robot arm for teat cup attachment, which has been described elsewhere in detail (16), was pneumatically driven at low pressure so that contact forces with the cow were limited to 150 N. Teats were located by a combination of stored coordinates and a local sensor. The positions of the teats were determined before the experiment by steering the robot to position the teat cup directly beneath each teat and recording the resultant Cartesian coordinates. The displacements of the flanks and rump of the cow were measured continuously by the positions of pneumatically actuated paddles lightly pressed against the cow. The coordinates of the teats were stored with reference to the positions of the flank and rump sensors. When a cow changed position in the stall, the teat positions were adjusted automatically. The local sensor consisted of an array of pulsed light beams mounted in a plane 80 mm times 80 mm over the mouth of the teat cup. As the array was offered up, the teat broke the beams, allowing the robot to center the teat cup beneath the teat end. Attachment of the teat cup was determined by monitoring of vacuum level in the milk pipe.

If the array of light beams failed to detect an obstruction after 10 s, the array and teat cup were lowered and offered up again once more. If after 10 s the array again failed to detect the presence of the teat, the teat cup was released from the gripper and the robot proceeded to the next teat cup. The teat cups were retained on the teat by the vacuum of the milking machine. Each teat cup was attached via a milk pipe to a recorder jar mounted on a strain beam. The milk flow into each jar was calculated from the rate of increase in strain. Vacuum was shut off, and the teat cup removed automatically, 20 s after milk flow from the individual teat declined below 200 ml/min.

Once all teat cups had been removed, the feed trough was retracted, gate G was opened, and the cow was allowed to leave. An exit race sprayer to disinfect the teats (14) was activated by beams f and g as the cow left the stall. Cows were allowed 5 min to leave the stall after which they were prompted to move by the experimenter.

Nine Friesian-Holstein cows were randomly selected from 60 cows that met the criteria of not being lame or unhealthy and having a milk yield greater than 30 L/d. None of the cows had previously been milked automatically.

Data were not recorded for the first 2 d as the cows became familiar with the system. Two treatments were then imposed. For the first period of 5 d (treatment 1, fixed interval presentation), the cows were presented manually to the entrance of the identification stall starting at 0730, 1330, and 1930 h (milking intervals of 12, 6, and 6 h). At all other times, the cows were able to move to the feed manger through the identification stall without hindrance and return to the lying area via gate J.

For the second period of 5 d (treatment 2, voluntary milking as a function of feeding frequency) the cows had free access to the entrance of the identification stall at all times. The milking system was available for the use of the cows from 0600 to 2359 h with breaks for cleaning at 0900 to 1000 h and 1530 to 1600 h. When the milking system was not operating (0000 to 0600 h), the gates were tied back to allow the cows to move to the feed manger unhindered. Cows were not allowed reentry into the milking stall within 4 h of the previous milking.

The sequence of events was the same for each cow at milking. The experimenters only interfered with the actions of the cow or robot when inaction would have compromised the continuation of the experiment or the welfare of the cow. For example, if a teat cup was not attached by the robot, the event was recorded, and the teat cup was attached manually.

The following system and cow responses were recorded manually: the cow's action in climbing on the front step, whether each rear teat was visible in front of the corresponding hind leg, the success or failure of attachment to each teat, and whether the cow left the stall voluntarily within 5 min of opening the gates at the end of milking. In the event of a failure, more detailed observations were recorded.

The data recorded automatically by the robot control system included the identity of the cow and the time of attendance and departure, the time taken to attach each teat cup, and the coordinates of attachment for each teat.

## RESULTS

The total number of visits by the cows to the milking stall was 135 on treatment 1 and 144 on treatment 2. The total number of visits during which human intervention was required was 77 (27%). The total number of attempted teat cup attachments for both treatments was 1116 of which 162 failed (14%). A visit or attachment attempt was deemed to be a failure if any part of the system prevented complete automatic attachment. Failures are categorized in Table 2.

Some of the causes of failure were trivial. For example, on at least three occasions, start-up problems prevented the system from working properly for the first cow in the morning.

Engineering problems have been divided into those that resulted in the robot arm failing to locate the teat cup beneath the teat (B) and those that occurred after the teat cup was offered up in the correct position (G).

In cases of contact between the cow and the robot, if the cow's leg moved to make the contact or if the cow stood on the milk line, the incident was recorded as a kick (8 of 1116); otherwise, as a collision (2 of 1116). Each kicking incident occurred very rapidly and usually set off a series of other failures. In one incident, the cow's leg obstructed attachment to the third teat; the cow then stood on the milk line of the fourth teat cup after being in contact with the robot. A visit failure, shown in parentheses in Table 2, was always ascribed

TABLE 2. Result of teat cup attachment and milking visit (in parentheses) for both treatments.

| | Cow | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
| Success | 102 (21) | 120 (26) | 117 (25) | 97 (19) | 99 (20) | 119 (28) | 95 (15) | 100 (23) | 105 (24) | 954 (201) |
| Failure[1] | | | | | | | | | | |
| A | 10 (6) | 11 (6) | 8 (5) | 24 (11) | 9 (5) | 13 (5) | 8 (6) | 4 (2) | | 87 (45) |
| B | 3 (2) | | 2 (2) | 3 (1) | 5 (1) | | 5 (2) | 4 (1) | 5 (2) | 27 (11) |
| C | | | | | | | 13 (7) | 1 (1) | 4 (1) | 18 (9) |
| D | | | | | | | 1 (0) | | | 1 (0) |
| E | | 1 (1) | | | 3 (2) | | 1 (0) | 3 (2) | | 8 (5) |
| F | | | 1 (0) | | 1 (1) | | | | | 2 (1) |
| G | 1 (0) | | | | | | 1 (0) | 5 (2) | 2 (2) | 9 (4) |
| H | | | | | 2 (0) | | | | | 2 (0) |
| I | 4 (1) | | | | 5 (2) | | | 3 (0) | | 12 (3) |
| Totals | 120 (30) | 132 (33) | 128 (32) | 124 (31) | 124 (31) | 132 (33) | 120 (30) | 120 (30) | 116 (29) | |

[1]Failure modes: A, positional (not clear whether conceptual or engineering); B, operation or engineering did not perform to specification; C, cow failed to climb on the step; D, cow moved too fast for the robot to track; E, cow kicked the robot arm or stood on milk line; F, robot unable to reach attachment position because of collision with a static leg; G, robot reached correct attachment position but teat cup was not attached or failed to milk; H, aborted by operator to avoid damage to cow or robot; and I, missing value. The first mode of failure on a visit was classified as the mode of failure for the entire visit. Thus, some teat cup failures were not the cause of a visit failure because they were an attempt during a visit that had already failed for another reason. Total number of visits was 279; total attachment attempts was 1116.

TABLE 3. Times for cow movement through the automatic milking system.

| System area or function | Minimum | Maximum | Mean | SD | Adjusted mean[1] | SD |
|---|---|---|---|---|---|---|
| Gate A > E | .1 | 42.3 | 2.6 | 2.1 | 1.8 | 1.7 |
| Udder preparation | .3 | | .3 | .3 | | |
| Attachment and milking | 4.8 | | 4.8 | .7 | 4.8 | |
| End of milking > H | .1 | 16.3 | 3.3 | 1.8 | 2.9 | 1.6 |
| Total visit time | 5.3 | 64.3 | 11.0 | | 9.8 | |
| Nonmilking visit, gate A > J | .1 | 50.3 | 2.5 | 3.8 | 1.0 | 2.2 |

[1]On two occasions, cows stopped in the system for considerable periods (>60 min); excluding these two outlying values gives a more accurate adjusted mean.

to the first mode of failure to occur because the subsequent failures were usually a result of a sequence of events set in motion by the first failure.

On six visits (failure C, Table 2), a cow failed to place her front feet on the step before the robot began its attachment sequence, which caused the robot to miss the teats because the original estimated teat positions were measured with the cow on the step. One cow was involved in five of the six occasions.

During treatment 1, cow movement was prompted by the experimenters. During treatment 2, the time that cows spent in parts of the system was variable (Table 3). Cows on some occasions spent long periods standing within the selection system. The longest time recorded for one cow to pass through the system was 64.3 min, and the shortest was 5.9 min (including milking). The mean attachment time per teat was 20.4 s, and the mean time for attaching all four teat cups 82 s. On 13 occasions (9% of total), a cow needed encouragement to leave the stall after 5 min had elapsed from the end of milking. One of the five cows exhibiting this behavior was responsible for 5 occurrences.

The main features of cow behavior under treatment 2 are recorded in Table 4. The cows all showed similar attendance behavior except for cow 9.

The mean number of visits during each hour of the day is shown in Figure 2. Attendance peaked early in the morning, but cows became

TABLE 4. Features of cow behavior for the 5 d of treatment 2.

| Cow | Parity | Mean milkings | Mean diversions | Mean visits to feed area | Mean milking interval during the 18 h/d | Mean duration of milking visits |
|---|---|---|---|---|---|---|
| | | ( /d) | | | (h) | (min) |
| 1 | 6 | 3.0 | 2.6 | 5.4 | 5.5 | 11.9 |
| 2 | 3 | 3.6 | 2.6 | 6.2 | 5.2 | 15.3 |
| 3 | 3 | 3.4 | 2.8 | 6.0 | 5.6 | 8.5 |
| 4 | 3 | 3.2 | 3.8 | 5.6 | 5.5 | 12.1 |
| 5 | 3 | 3.2 | 4.6 | 8.0 | 5.1 | 9.3 |
| 6 | 4 | 3.6 | 3.6 | 7.2 | 5.0 | 9.2 |
| 7 | 4 | 3.2 | 1.4 | 4.6 | 5.6 | 8.9 |
| 8 | 7 | 3.0 | 2.4 | 5.4 | 5.7 | 14.2 |
| 9 | 6 | 2.6 | .6 | 3.2 | 8.9 | 9.3 |
| Overall mean | 4.3 | 3.2 | 2.6 | 5.7 | 5.8 | 10.9 |
| SD | | .3 | 1.2 | 1.4 | 1.2 | 2.5 |
| Overall mean[1] | | 3.3 | 2.9 | 6.0 | 5.4 | NA[2] |
| SD[1] | | .2 | .9 | 1.1 | .3 | NA |

[1]These values exclude those of cow 9, whose behavior may not have been typical.

[2]NA = Not available.

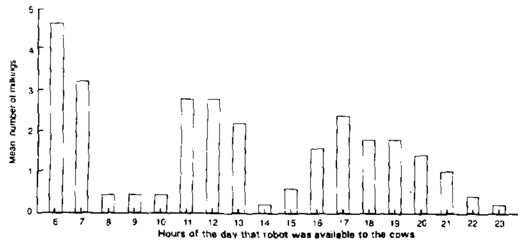


Figure 2. Mean hourly distribution of voluntary milkings over 5 d under treatment 2.

less synchronized in their attendance as the day progressed. There were few visits for feeding between 0000 and 0600 h (a mean of .3 visits for all cows per night), which suggests that the milking attendance pattern would have been little affected if the milking system had been available between these hours.

## DISCUSSION

The Silsoe Research Institute automatic milking system can locate teats and attach teat cups to cows attending voluntarily for milking. The system successfully milked completely automatically on 72% of occasions and located and attached teat cups to 85% of teats. The results of this trial showed an improvement over the previous success rate (3); results included failures to attach caused by some cow responses that were not reported in the earlier trial. The difference between the automatic milking systems of the two trials only included some minor changes to engineering detail, and so a major improvement in performance had not been expected. Further trials are necessary to determine the repeatability of the results.

The causes of failure that can be definitely assigned to the response of the cow (not standing on the front step, kicking the robot, moving too fast for attachment, and colliding with the robot C, D, E, and F in Table 2) amount to 17% of the failures to attach all four teat cups and 31% of failures to attach individual teat cups. These conceptual failures must be considered in the design of future robotic systems. Some of the failures may not occur as cows become more familiar with the system, but practical automatic milking systems should not require the culling of large numbers of cows for behavior. The system should fit the cow, not vice versa.

The motivation of the cows to enter the identification stall could not be determined from this experiment. Cow 9 was obviously not motivated to attend frequently (Table 4). On one occasion, she had to be manually fetched shortly before midnight to ensure that she was milked twice in the day. However, her reluctance to attend was not manifest in her behavior in the stall. She never caused the robot to fail to attach and consequently had the highest individual attachment rate (94%).

The time that cows took to move through the system showed considerable variation (Table 3). The longest times were spent in the identification stall, suggesting that a degree of uncertainty was created for the cow intending to go in one direction (to feed) being diverted to another (to be milked). A different diversion system might reduce uncertainty by giving the cows an unambiguous route through the system. For example, all cows could pass through a stall where they could be milked if required. Multiple stalls served by one robot could be used, thus removing the unpredictability from the outcome of a visit to the identification stall.

Cows were sometimes reluctant to leave the stall. A similar result was obtained by Metz-Stefanowska et al. (10) with a different system. Throughput of the milking system could be improved more by reducing the time cows linger after milking from the mean (3.3 min) toward the minimum (.1 min) than from increasing the speed of teat cup attachment.

The mean number of cow visits to eat silage was six per day, which is less than that reported under conventional conditions (12). Winter et al. (18) showed that dispensing fresh forage in the feed manger (Figure 1) tended to synchronize feeding visits. Forage was dispensed in this trial at 0700 h, after milking had started, but this activity may have prompted cows to want to enter the system earlier than might otherwise have been the case. The capacity of the experimental system (5 to 6 cows could be milked per hour; mean visit duration 11 min; Table 3) may have tended to delay the first silage feeding of the day for some cows. This delay may have affected the timing of subsequent feeding visits. Some cows may have had to wait to enter the system, which may have been the cause for the reduced visits to the feed manger. Further work is needed to explore the relationship among the controlled circulation system, cow feeding behavior, and forage consumption to enable a system to be designed that encourages frequent attendance for milking, high forage consumption, and a minimum of standing and waiting.

In treatment 2, with voluntary attendance, the cows were all milked within 2 h of the time that gates opened in the morning. One potential benefit of automatic milking to improve cow welfare and productivity is a reduction in the standing time of cows before and after milking (17). Ideally cows should be milked within a few minutes of approaching the stall. This ideal could be achieved either by providing a multiplicity of stalls or by finding methods of spreading the pattern of attendance throughout the day and night.

Teat cup attachment inevitably failed when the cow did not stand on the front step because the teat position coordinates were recorded for the cow standing on the step.

The positional failures may have been either because the location of the teat has not been determined correctly or because the robot has not moved to the determined teat position. Further investigation is needed into why some cows had more positional failures than others. If the cause of positional failure is common to many cows, then teat cup attachment can only be assured by developing an improved teat location method.

## CONCLUSIONS

In this experiment, the Silsoe Research Institute automatic milking system successfully attached teat cups to 85% of teats and completely milked cows presenting themselves to it on 72% of all visits. Cows, offered unrestricted access to an automatic milking system through a managed circulatory system, were milked an average of 3.2 times per 18-h day. Positional and engineering errors had more importance in affecting teat cup attachment than did cow behavior, which prevented successful milking on only 2.2% of attempts. Further research is required to determine the cause of positional errors, to increase the success of teat cup attachment, and to recover from occasional cow responses, such as failure to enter the stall fully, kicks, and rapid movements. Behavioral research is needed to determine whether automatic control of cow traffic is essential to ensure the regular attendance of all cows throughout lactation and to improve the speed with which cows move through the automatic milking system.

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