

Design of automatic milking system for use in pasture-based systems

End of Project Report-5238

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1. Summary

A commercial vision system was successful in identifying target artificial teats in various and demanding scenarios, but the system is very prone to making false identifications.

A robotic manipulator capable of the simultaneous handling of four milking cups has been designed.

The end-effector profile is sufficiently compact to allow access between the rear legs of the cow while enabling full access to all four teats for application of milking cups.

The positioning response of the end-effector is satisfactory for accommodating small changes in teat position during milking cup application.

2. Introduction

Labour studies (O'Brien *et al.*, 2001) have shown that the milking process accounted for 37% of dairy labour input over a 12 month period. Future expansion of herd size on dairy farms will be required to maintain viability. This expansion will have important implications for labour requirements on dairy farms. Since farm labour is difficult to acquire farmers will look to automation in order to cope with increased cow numbers. Automatic milking systems (AMS) have been available commercially since the early 1990s, and have proved relatively successful in implementing the voluntary milking method. AMS represents complete automation of the milking process, eliminating manual labour from the milking process and freeing the farmer from the strict milking schedule of conventional dairy farming. However, the expected benefits in terms of increased productivity and profitability have not materialized for several reasons.

Capital investment is high compared to conventional parlours; a double-unit AMS handling 120 cows per day is similar in cost to a rotary parlour that can handle 200 cows per hour.

Capacity is low, typically 7.5 cows/AMS unit/h, compared to 120 cows/h for a standard high capacity parlour.

Due to low capacity, return on capital investment is low and profitability is similar or lower than conventional milking systems, particularly for larger enterprises.

More complex technology reduces the ability of the farmer to repair faults, increasing reliance on maintenance services.

AMS is not universally applicable within the dairy industry and functions best in zero-grazing systems, where the cows are permanently housed during the lactation period. On zero-

grazing farms, grass is cut during the day and fed to the cows in the barn along with concentrates, rather than allowing the cows to graze at pasture. Zero-grazing is common in countries such as the Netherlands where land is at a premium and all available pasture is utilized for grass production. However countries such as Ireland, the UK and New Zealand typically operate pasture-grazing systems, in which the cows are brought in groups to the milking parlour for milking. Conversion to zero-grazing would represent a complete and expensive systemic change for the Irish farmer, complicated by the fact that the farmer must maintain normal milk production during the changeover and thus operate two separate milking systems in parallel for a period. A study in the Netherlands (Ketelaar-de Lauwere, 2000) indicated that AMS may be used with local pasture grazing up to 400m from the milking unit, however practical attempts (as observed by Teagasc staff in Ireland and New Zealand) to adapt AMS to the pasture-grazing system have been unsuccessful, primarily because grazing is not always available adjacent to the milking parlour and cows would not voluntarily attend the milking unit from remote pasture.

Objective:

Development of a teat identification and location system in conjunction with a robotic applicator

The main objective of the project was to design a robot arm and teat sensing system for use in a automated rotary milking unit where the milking units are attached and the platform advanced automatically. This gives better utilization of the AMS system and should allow the system to be viable in pasture based systems of milk production.

The development of the robotic applicator was broken down into two parts; the first element requires the sensing and location of the animal teats, while the second requires the manipulation and application of the cups to the teats. The project was initiated by undertaking a review of the technology currently available in the milking sector and by also considering other technologies that will lend themselves to this application.

3. Development of teat identification and Location system

3.1 Introduction

The primary sensing solution employed in existing AMS is a laser based vision system. A single camera is used to detect the location of a laser stripe that is incident on a teat. The location of the stripe in the camera image, coupled with the relative distances between the laser and the camera and the angles of incidence is used to triangulate the position of the teat.

The 'IceTracker', an IceRobotics (IceRobotics · Logan Building · Roslin BioCentre · Roslin · Midlothian EH25 9TT · Scotland UK) product was analyzed to determine whether it is suitable for providing simultaneous teat coordinates to the cup application robot. The 'IceTracker', is a machine vision sensor for real time tracking of cow teats. It is designed to acquire and track teats in real time, reporting the 3D position of the teat ends at a frequency of 10Hz with an accuracy of $\pm 5\text{mm}$. Its performance was assessed based on its ability to correctly identify teats in the scene and also on the accuracy of position estimates that it provides for each teat.

The system operates using a client server interface to communicate with the user. Instructions and operating parameters are passed to the server from the client; the server returns images from the cameras as well as the position coordinates of the teats identified in the images. Fig. 1 illustrates the topology of the system. The IceRobotics system is made up

of the cameras and the server, a separate module with which an outside client communicates.

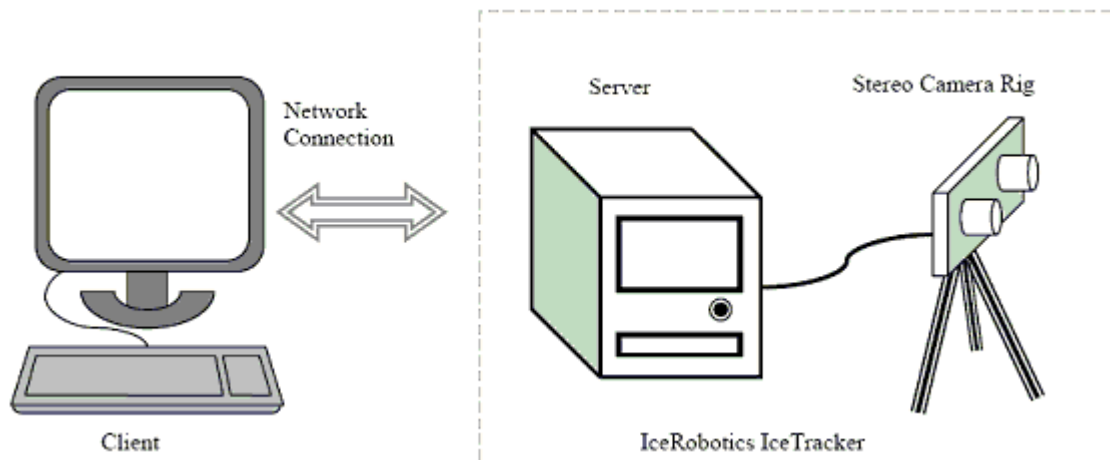


Figure 1. Illustration of IceTracker system setup

3.2 Materials and methods

Two PCB mounted RGB colour CCD cameras make up the stereo camera rig. They each have lenses with focal length 3.5mm. The resolution of the cameras is 640x480 pixels. The cameras are mounted on two separate PCBs connected by a flexible ribbon cable. This allows the cameras to be moved freely relative to each other within the confines of the cable. Fig. 2 shows the camera rig.

The ability of the IceRobotics Teat Tracker to identify teats was explored for nine particular circumstances. The performance is judged on the ability to successfully identify a target teat. A successful identification occurs when the system correctly identifies corresponding image points in the left and right images of the stereo pair belonging to the same teat target.

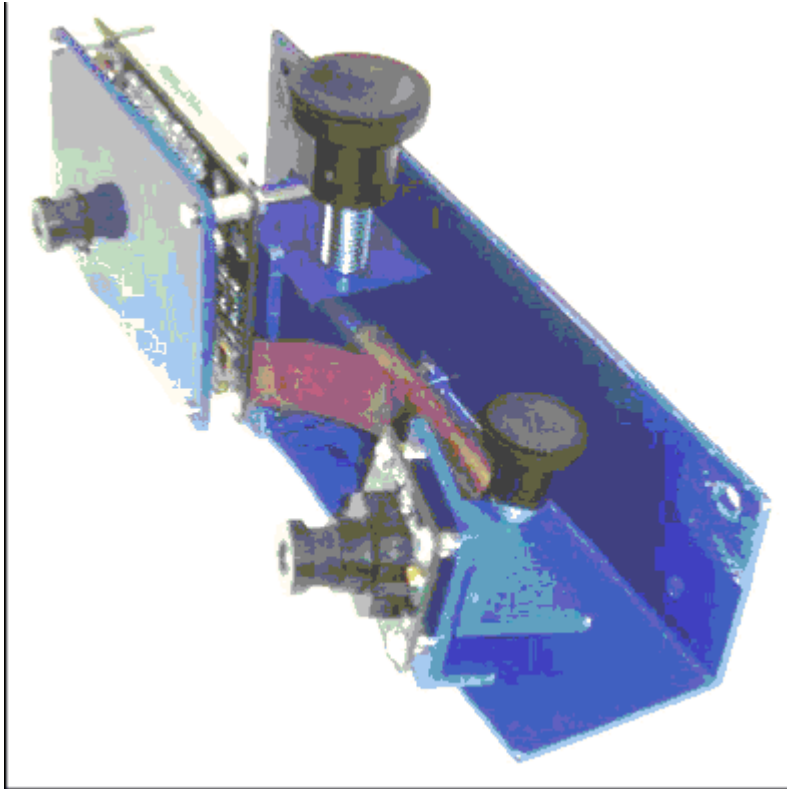


Figure 2. Stereo Camera Rig

3.3 Results and Discussion

It was found that in general, the system is capable of producing desirable results in all of the defined setup conditions, but it cannot reproduce them reliably. The ideal scenario is the benchmark on which all other scenarios are based. The scene contains four well-illuminated teats in a standard udder formation, located within the target region of the vision system. All teats are clearly defined in the stereo images and none of the teats are obscured in either view. The background scene is neutral; there are no teat-like objects or artifacts in the images, due to the background. In this first scenario the system successfully identifies all of the target teats.

The second scenario involves all the teats being partially obscured, in both camera views, either allowing the tops or the bottoms of the teats to be seen by the cameras. The vision system must have a view of the teat end (the bottom) in order for it to identify a teat.

The third scenario investigates the systems ability to identify a teat that is partially occluded in either one of the camera views or in both camera views. The system is still capable of identifying partially occluded teats when the bottom of the teat can be seen in both the left and right camera views.

In the fourth scenario an object which approximates the shape of a teat is introduced to the background of the scene, outside of the target region. The system falsely identifies such an object as a teat. Corresponding points of the non-teat object in the stereo images will result in a disparity that is too small for a teat within the target region (the object is outside of the target region, it's depth in the image is too great). Thus, in falsely identifying the object, the system makes false correspondences between the non-teat object in one image, and another different teat shaped object in the other image of the stereo pair.

The fifth scenario has a non teat shaped object within the target region. The results of this test demonstrate the shortcoming of the IceRobotics system. The object is falsely identified as a teat. There is no clear reason as to why the system chose the object that doesn't resemble a teat in favour of an unidentified target teat in the centre of the target region being well illuminated and clearly defined in the camera images.

The system performs well in identifying the closely bunched teats in the sixth scenario. The occlusions are not an issue provided the bottom of the teats can be seen by both cameras.

The outcome of the seventh scenario has bearing on the teat angle extraction algorithm. The scenario investigates the ability of the system to identify a teat that is not pointed straight down. The system is seen to perform equally well in identifying angled teats as it does with non angled teats. Teats angled both towards and away from the cameras, and angled to the left and to the right in the images are successfully identified. This result is crucial as the basis of extending the systems functionality to provide teat angle measurements is that the system is able to first locate the teat in the images.

In scenario eight, the teats are moving within the target region. The system can track targets in approximate real time, providing an updated location for an identified teat every 1/10 of a second. The stereo pairs of images are captured instantaneously, and for each instance the system identifies the teats from the static images captured.

The final scenario involves objects moving in the background scene. The system is prone to misidentifications in this case due to the fact that if there are regular movements of multiple objects in the background scene, it is likely the objects will interact in such a way as to appear to be a teat in the camera images. The output of the system is seen to be unstable and unpredictable. Even in ideal conditions (scenario one) a minor change in the position or in the orientation of the teats can lead to the system failing to identify a teat that was being successfully tracked prior to the changes. Changes in the position or in the intensity of the light source are seen to have the same effect on the output stability. There is indecision in the coordinate outputs of the system even when all targets have been correctly identified in a static scene with constant illumination. All three component values of the coordinate triples are seen to fluctuate, usually within a range of $\pm 1\text{mm}$, with the biggest fluctuations being seen for the Z-component.

3.4 Conclusions

The overall assessment of the systems ability to successfully identify target teats is that it is capable of identifying teats in various and demanding scenarios, but, the system is very prone to making false identifications.

4. Design of a robotic manipulator for automatic application of milking cups

4.1 Introduction

In all of the existing automated systems, each of the four milking cups are individually attached to the teats. The teat identification system provides the location of a single teat for attachment purposes. This process is completed four times per cow and incurs a large time overhead. Fig. 3 contains a prototype design for a manipulator arm end-effector intended to simultaneously attach all four milking cups to an animal. The teat cup application time constrains the utilization of a rotary carousel. A typical operator can manually apply the cluster of four teat cups to a cow as it passes in under ten seconds. A traditional AMS usually takes around a minute to complete the teat cup application stage. There is no onus on these systems to quickly apply the cups since there isn't a dramatic effect on throughput

(The attachment time is a small fraction of the milking time, for which the AMS is occupied and the milking is spread out over a 24 hour period).

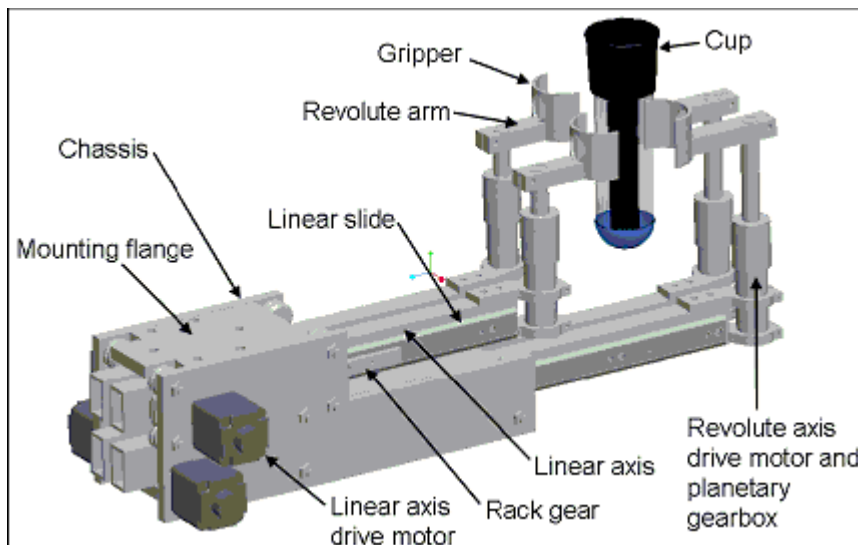


Figure 3. End effector to simultaneously attach four milking cups to a cow

4.2 Material and Methods

Assumptions

The following conditions were assumed:

Teat coordinates available in real-time

Rear leg movement restricted during application

Milking cup cluster is presented for pick-up at a known location

The design seen in Fig. 3 has four linear actuators. Attached to each actuator by a rotational actuator is a suction plate for holding a milking cup. The design allows the end effector to manoeuvre the cups independently in a horizontal plane beneath the udder of a cow. Once all the cups are positioned beneath the teats, the four cups are moved vertically upwards to complete the attachment. The upward actuation is provided by the manipulator arm to which the end effector is attached. There is no independent actuation of the four teat cups along the vertical axis. The angle at which a teat cup is held is fixed. The central axes of all four cups remain parallel to the vertical axis whilst under the cow during the attachment process. Independent movement of the cups in the horizontal plane allows the individual adjustment of the cups during the vertical actuation of the end effector for ease of attachment to a teat orientated at a large angle to the vertical. A cup can be adjusted horizontally so that the centre of the cup opening traverses the central axis of the teat as the cup moves up.

To enable the four teat cups to be attached simultaneously, the teat identification and location system must be able to provide the 3D position and orientation of each teat instantaneously in approximate real time. It is a design requirement that the 3D position of teats be known to within an accuracy of $\pm 5\text{mm}$ and their orientation angles known to within $\pm 5^\circ$.

Workspace Analysis

Parameters and constraints for the manipulator workspace were determined by observation and measurement in an operating rotary parlour (Dairymaster Swiftflo Revolver). The distance between hocks and the distance from lowest rear teat to floor were measured for 35 cows during milking on the rotary carousel, with worst-case parameters established by selection of cows with poor udder presentation (hocks and pins closer together and low teats). Biometric data for teat-spacing were obtained from literature (Kuczaj *et al.*, 2000). The manipulator working envelope was modelled by merging measurements and observed constraints from the subject animals with stall and milking equipment dimensions and positions.

Approach Analysis

Approach methods for milking cup application were selected for minimal interference with the conventional rotary parlour. Milking cups may be attached from the side, rear or underneath the cow and either sequentially, two-at-a-time or with all four applied simultaneously. The speed of application was established using existing manual methods as a benchmark while the size and geometry were defined based on workspace constraints and kinematic approach analysis.

Design requirements were extracted from the analysis, and a design specification was generated.

Conceptual Design

Conceptual designs were generated to fulfil the design requirements and the final design was selected using concept weighting methodology.

Detailed Design

Design and analysis of the manipulator end-effector (end-of-arm tooling) were performed using 3D CAD/CAE software, and software model data were utilised in validating the design and specifying an appropriate 6-axis handling robot. Full position feedback was specified for end-effector axis drives to give accurate positioning and flexible control, while vacuum technology was employed to retain the milking cups. Control was affected using distributed position controllers linked to a central control PC.

4.3 Results and Discussion

The designed end-effector comprises four wrist-forearm mechanisms, each possessing 2 degrees of freedom and handling a single milking cup. The minimum access corridor between rear legs is 130mm wide and 280mm high. Teats spaced up to 220mm apart may be accessed. Fig. 4 shows the results of end-effector step response tests using simulated teat positions. Positioning times of <180 ms within an area of 20 mm and <340ms within an area of 60mm were observed. The results indicate that small changes in teat location (<20mm) may be tracked at a position update rate of approximately 200 ms.

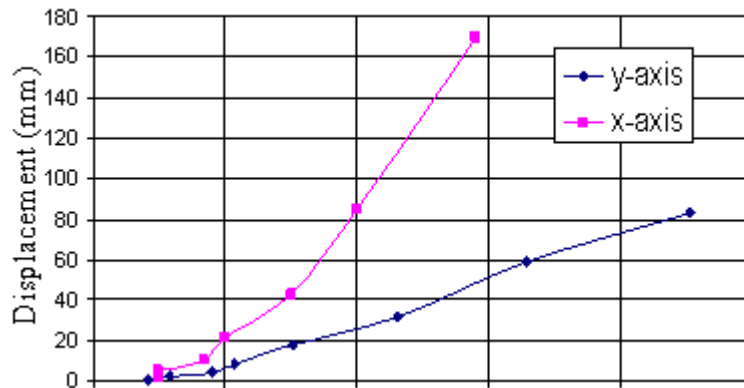


Figure 4. End-effector positioning response per-axis

5.3 Conclusions

A robotic manipulator capable of the simultaneous handling of four milking cups has been designed. The end-effector profile is sufficiently compact to allow access between the rear legs of the cow while enabling full access to all four teats for application of milking cups. The positioning response of the end-effector is satisfactory for accommodating small changes in teat position during milking cup application. The robotic manipulator is a suitable platform for developing and testing application algorithms for high-capacity AMS.

5. References

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6. Publications

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