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Development of a teat sensing system for robotic milking by combining thermal imaging and stereovision technique

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ABSTRACT

The robotic application of milking cluster to the udder of a cow in a rotary high capacity group milking system is a major challenge in automated milking. Application time and reliability are the main constraints. Manual application by an operator of a rotary milking system is of the order of 10 s and 100% reliable. Existing commercial automatic milking systems employ laser scanning technology. The teat cups are applied to each teat individually and the process can take up to 2 min. In order to achieve a more rapid simultaneous application of the four cups, the three dimensional locations of the four teats must be known in real time. In this paper, an innovative multimodal vision system combining optical stereovision and thermal imaging is developed. The two technologies were combined and calibrated into one vision system. Algorithms of detection of the teat and determination of their three dimensional position were also developed. Using a dummy thermal udder, laboratory tests were performed for various situations and the system was evaluated from the point of view of accuracy and robustness. Results showed that the system could locate accurately in less than one second the three dimensional position coordinates of the four teats. This speed of detection is much faster than any existing technology employed with automatic milking and could be an alternative approach of sensing the teats, which can increase the yield of rotary milking system. In terms of robustness, the system achieved promising results by retrieving the position of the teats with challenging configurations including touching and overlapping teats. Further optimisation is proposed to increase the robustness prior to in-situ trials with real cows. The overall results demonstrated that it is possible to increase the efficiency of the stereovision technique for teat location by introducing thermal imaging.

1. Introduction

In order to remain viable, dairy farmers need to increase their herd size without significant additional labour costs. The most labour intensive part of dairy farming is the milking process which is responsible for one third of the total labour cost (O'Brien et al., 2001). A recent study in New Zealand concluded that milking accounts for up to 70% of all labour on a dairy farm (Ohnstad and Jago, 2007). Moreover, the dairy industry is already experiencing a labour shortage (Dairy Australia, 2006) and the situation might become unsustainable in the future (Garcia and Fulkerson, 2005). In countries where cows are pasture-based like USA, Australia, New Zealand, Ireland and UK, existing automatic milking systems (AMS) are unsuitable for use with grazing because the higher milking frequency is difficult to implement. The farmers would need to install more than one AMS; this significantly increases the capital outlay involved for a farm moving to automatic milking. Also, the dependence on concentrate food offsets the savings incurred with grazing dairy farmers. Furthermore, a recent study in the Netherlands showed that famers who use AMS did not experience a clear reduction of labour costs as opposed to farmers employing conventional milking processes (Steeneveld et al., 2012). Where group-wise milking is performed, large herd sizes are dealt with most efficiently using the rotary milking systems. These parlours afford high animal throughput and most aspects of the process are automated. However milking cluster attachment is still performed manually and thus requires constant operator attendance. Removal of the operator will reduce labour costs and could also entail a totally automated milking process thus freeing up time for the farmer and giving him significant social benefits.

Existing automated milking systems (AMS) are already available where the entire process including teat cup attachment is performed autonomously. These systems are shed based

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requiring that the animals are permanently housed and are milked on a voluntary basis one animal at a time. Each animal attends the milking stall twice a day where a robot takes up to 2 min to apply the four teat cup, called also milking cluster, to the teats. By contrast, the manual application of teat cups on the rotary parlour takes between 5 and 10 s per animal. Consequently, the robotic technology employed in AMS is not suitable for adaptation to the rotary milking system. For high-speed cup application, a highly dexterous robot is required combined with a sensing system that can determine the position of all four teats in real time. This paper reports on the development of a sensing system suitable for integration into an AMS for use on a rotary parlour.

1.1. Automated teat detection

A teat sensing system should be able to determine exactly the space coordinates and fast enough for the application to be successful while being invasive to the animal. The animal should not be touched during the location process in order to avoid provoking uncontrolled movements. The sensor system must also be appropriate for the particular environmental conditions at the implementation site, and be robust and reliable (Artmann, 1997).

Manual application of the teat cups by the operator of a rotary milking system is of the order of 10 s and of course 100% reliable. As a design goal the automated attachment should not take any longer than 20 s to maintain high productivity. Although cow movement during the attachment process is limited, there is a need for real-time detection so that the system refreshes the positions of the teats every 1–2 s. Therefore, considering this condition as well as the requirements of reliability and accuracy, a target of 1 to 2 s to detect the four teats was set with an accuracy of 5 mm (detection error less than 5 mm).

All sensing systems used in the commercial AMS are laser/vision based systems. A single camera is used for the detection of the laser stripe location that is incident on a teat. In order to triangulate the position of the teat, the location of the stripe in the camera image is coupled with the relative distances between the laser and the camera and the angles of incidence (Lars and Mats, 1998). Such a system can provide reliable and accurate information regarding the position of a teat but it can only detect a single teat at a time. Once a teat has been successfully located and the teat cup is applied the system moves on to the next teat. This procedure is repeated until all teat cups of the milking cluster are attached. For the current approach, the positions of all four teats are required simultaneously.

Recent development in AMS industry resulted in an increase of the time detection of teats using laser scanner approach. In 2010, DeLaval announced the development of the first fully Automatic Milking Rotary (AMR) "DeLaval AMR™" with initial tests at pasture based herd in Tasmania in 2011 (DeLaval, 2012). The system consists in a rotary carousel milking parlour with up to five robots positioned inside the parlour. The application of the teat cups is made by two robots and takes approximately 1 min to apply the four teat cups, in comparison to around 10 s when a human applies manually the teat cups. The system combines historic position data and a laser scanner to identify the positions of the four teats. DeLaval states that the system is able to milk up to 90 cows per hour and that it is suitable for herds of up to 300 cows (DeLaval, 2011). Traditional rotary milking systems have a yield of between 120 and 300 cows per hour. The efficiency of the system can be improved if the time of location and application of the teat cups is decreased. It has been highlighted previously that using a vision system that can instantly locate the positions of the four teats would help in a approaching the ten seconds time base (Frost et al., 2004).

Other approaches employed to locate the teats were conductivity sensors (Akerman, 1980) and mechanical contact sensors (Artmann and Schillingmann, 1990). However, these techniques were quickly dropped as it can hurt the animal in addition to the unwanted movement of the cows that they can provoke (Artmann, 1997). During the eighties, successful attempts using image processing with laser scanning techniques (Montalescot, 1987) and ultrasonic (US) range finding devices and/or optical sensors were realised (Torsius, 1988). A number of processes are available for US distance measurement (Artmann et al., 1990; Artmann and Schillingmann, 1990); the exact teat location is determined by triangulation using two sensors from a sensor array, arranged so that the US search area encompasses the teat region. Laboratory tests showed that with this arrangement it is possible to measure to an accuracy of about 1 mm. This method was used in the Duvelsdorf AMS (Dilck, 1992). Greater success was achieved with these systems in conjunction with a database of relative teat configurations. Historical knowledge of relative teat position helped to reduce the amount of time needed to identify all four teats consecutively.

A limited amount of work has been conducted using thermal characteristics of the udder region (Ordolff, 1984), however, at the time thermal technology was very expensive, very slow and was not used commercially. Previous observations with thermal camera of the udder and teats of cows have shown that the area presents higher temperature than rest of the body (FLIR Systems, 2014). This strong heat signature of the adder area have been confirmed by in-field observation as part of this study,[1] see Fig. 1.

Frost et al. in Silsoe Research institute in the U.K. published several papers over the last twenty years describing the development of a pneumatic robot for teat cup attachment (Frost et al., 1993,2000,2004). The system uses three sources of information to define the locations of the teats prior to the application of the teat cups: stored teat position, information about the position and the movement of the cow in the stall and a local sensor above the teat cup. The stored teat position is saved from previous visits of the cow to the stall, while data about the position of the cow is gathered from three linear potentiometers placed in contact with the cow in the stall, finally, the local sensor at the teat cup consists of a matrix of light beams that is used to confirm that the teat is aligned inside the teat cup. The potentiometers have been discarded in later versions of the system and replaced by a vision system and image analysis routine (Frost et al., 2000).

In earlier work (Hunt Duffy, 2006), the performance of a commercial stereovision system was assessed in terms of success in identifying teats in the images and accuracy in determining teat position. It was found that false identifications were made of non teat-shaped objects within the target region and of objects resembling teat proportions in the background of the scene but outside of the target region. In Fig. 2 an object was placed beside four phantom teats and was identified and selected as a teat in preference to one of the other teats. This type of mistake is likely to occur in practise because of the presence of the robotic manipulator moving in and out of the working region.

Even with what seem to be neutral backgrounds, problems may arise. For instance, the shadow cast of a dummy teat was detected in some cases as the dummy teat. Consequently the system was noted to be extremely sensitive to lighting conditions. Overall, the reproducibility of the position estimates made by the system was variable and insufficient for robust teat tracking purposes (Hunt Duffy, 2006).

[1] A research visit to the Teagasc Moorepark Animal & Grassland Research and Innovation Centre, Fermoy, Ireland on October 15, 2007.