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Online Milk Sensing Issues for Automatic Milking

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Abstract. *A review of the state-of-the-art sensing technology for automatic milking systems (AMS) suggests that while the sensing systems currently being used lack the sensitivity for automated diversion of 'abnormal' milk, they do provide sufficient information for motivated dairy producers to achieve milk quality that meets or exceeds national averages. Electrical conductivity and milk color are the most widely used on-line milk sensing methods and deviation in milk yield and milking interval are widely used supporting diagnostic techniques. A number of other methods using visible and other light spectra have shown promise in detecting milk abnormalities and measuring various components of milk. Several methods of measuring the Somatic Cell Count of milk at cow-side have been demonstrated and may be applied to AMS in the near future. Developments in AMS milk sensing systems point toward the use of inputs from a number of sources including milk composition, animal behaviors, and milking characteristics combined and analyzed by centralized 'smart' system to improve diagnostic accuracy.*

Keywords. Automatic Milking, milk sensing, biosensors, literature review

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Introduction

The introduction of automatic milking systems (AMS) is arguably the most significant technological change in the dairy industry since machine milking in the late 19th century. Much as milking machines did for previous generations of farmers; automatic milking systems have the potential to enhance quality of life for dairy producers and their cows as well as increase milk production and milk quality.

While the technical problems of automatic unit attachment have been largely solved and voluntary cow traffic has proved feasible, development of sensors and systems to detect and divert milk is the main technological challenge for AMS and an area of intensive research and development.

The primary difference between conventional and automatic milking systems is that AMS does not require that a person be present as each cow is milked. The human eye and judgment can no longer be depended on to assess the health of the cow and quality of her milk. Instead, the AMS and its array of sensors must be relied on to make these assessments. As will be seen through a review of AMS field studies, the technology currently being used is not advanced enough to rely on automatic diversion of milk, with the only exception being detection of blood in milk. This paper will review the state-of-the art in milk sensing for AM systems as well as some of the ideas and emerging technologies that may represent steps toward the "ideal" AM online sensory system.

The first and probably most important question that must be asked when developing a sensor for an AM systems is "what to sense?" While milk quality is perhaps the most demanding sensing task, there are a number of other critical tasks in the AM process that rely on sensors and logic systems. A review of sensor systems for milking robots, published by Artmann (1997), identified several distinct sensing tasks:

- Animal identification
- Teat location
- Monitoring AMS functions
    - Ensuring proper machine function
    - Protecting people and animals from injury
- Measuring milk quantity and composition
- Monitoring other aspects of Animal health

Sensors designed to provide information primarily for one of these tasks can also provide information to support other tasks, and successful systems use a network of sensing elements and a logic system to strengthen diagnostic accuracy and provide value-added management support systems. Koehler, et al. (2002) indicated that identification of infected quarters using conventional reasoning only was difficult and suggested that the use of fuzzy logic could improve the reliability of detection. The main topic of this review is sensing systems for milk quality, but as we shall see, information from other sources is already being incorporated into this decision process.

The development of sensing systems is fueled by the prospect of a commercially viable product (providing the market with management information at a price justified by the benefits) and are also highly influenced by the regulatory climate (what types of technology are allowable and/or mandatory). Pietersma and Hogeveen (2004) did a theoretical analysis of the costs associated

with discarding abnormal milk that suggested the specificity of an automated system to discard abnormal milk must be very high in order to prevent economic loss. In practice, sensing technology is used as a retrospective 'warning' system. Automated systems are used to develop 'attention' lists of cows with suspected milk quality problems. Because of insufficient specificity, human intervention is still required to confirm a diagnosis and make the decision to divert milk from individual cows at subsequent milkings. These methods have resulted in milk quality on AMS farms that is as good, or better, than that from farms using conventional milking technology at the bulk tank level. There are still concerns from regulatory agencies over the ability of AMS to divert milk from individual cows. This must be considered in the context of the methods available and used in conventional milking technology. Diversion of all milk with 'abnormalities' is not possible or practical with conventional milking technology that relies on visual inspection. AMS systems must provide reasonable assurance that gross abnormalities are not ignored. This has created the need for a more precise definition of the characteristics of 'abnormal' milk to fit into regulatory structures.

Visual inspection is capable of detecting gross abnormalities in milk composition (clots, flakes, or 'wateriness') and some substantial change in color due to blood in the milk or other gross changes due to changes in lactation physiology. Biosensing systems in general, respond to some change in the chemical composition, or changes in the visible or non-visible light transmission or reflection of the milk. The basis for detecting abnormal milk with biosensors is thus quite different than for visual inspection. Biosensors have the ability to detect smaller changes in the visible light spectrum than the human eye. Visual inspection cannot be used to detect changes in chemical composition or the non-visible light spectra. Biosensors thus have the capacity to be a much more sensitive detection system for milk quality than human visual inspection.

Rasmussen (2004) proposed language for the EU Hygiene Directive regarding milk AMS sensing…" *milk from an animal is checked for abnormalities by the milker or a method achieving similar results*…" and that …"*abnormal milk be defined based on milk homogeneity*". A reference method using a filter with a pore size of 0.1mm and visual inspection for clots was suggested. The definition of the 'abnormalities' in milk that require diversion may continue to evolve as sensor technology develops and presents the possibility of on-line measurement of more aspects of milk quality.

Field Studies

Field studies reporting on the efficacy of sensing systems and resulting milk quality from AM farms have appeared in the literature over the past decade. A brief summary of the field studies reported at the 2000 and 2002 conferences on automatic milking follows.

A review by Lind, et al. (2000) reported that as of 2000 there were not yet sufficiently effective methods available to monitor characteristics of milk automatically so as to divert milk from unhealthy cows. Rasmussen (2000) reported that detection of mastitis by automatic milking systems was mainly based on measurement of conductivity and these systems tested in Denmark in 2000 did not detect quarters with abnormal milk or high cell counts sufficiently well. Knappstein and Reichmuth (2000) reported on a study on a commercial farm and found that the combining deviation in milk yield and conductivity enhanced the detection rate of clinical mastitis, increased number of false positive alarms and suggested that specificity may be improved by using quarter level measurement. A study in northern Italy (Bronzo, et al. 2000) found that systems had clear limits in detecting subclinical mastitis and that changes in the threshold values used (or in algorithms) and/or in the performance of the conductivity sensors were needed to increase the suitability of automatic mastitis detection systems. A field study in

England on a commercial AMS that monitored conductivity changes on a quarter basis (Ohnstad, et al., 2000) found that 42% of cows had one “trigger” (increases in conductivity of 10% or more, when compared to the mean of that quarter over the previous 14 milkings) and that milk yield was lower and SCC higher cow-weeks with conductivity triggers. Trilk (2002) reported that in 2002 all commercial AMS in Europe still used conductivity as the only automatic method to obtain information regarding disorders of udder health and that a study at an experimental farm concluded that the EC system tested insufficient for practical use. De Jong, et al. (2003) reported that AMS users in North America widely practiced manual inspection of cows for mastitis detection, with inspection lists generated by deviations in daily milk yield (compared to a rolling average for individual cows), milking interval (time since last successful milking) and milk conductivity. Many farms reported that they were less likely to use milk conductivity data as they gained more experience with AMS.

A review of the field studies presented at the 2004 conference on automatic milking in Lelystad provides an indication of the speed of technological advancement. Studies on the efficacy of the methods to detect mastitis and poor milk quality on nine farms using two types of AMS by Hovinen, et al. (2004) concluded that the sensitivity of detection methods need to be improved. Binda, et al. (2004) reported that in 2004 many farmers were still reluctant to rely on electronic devices to monitor cow health status. Their study of subclinical mastitis detection by two commercial AM systems on 4 herds suggested that the current mastitis detection system must be improved in order to be applied efficiently. Bennedsgaard, et al. (2004) reported that in a study of 20 Danish Dairy herds, the methods used by operators to identify cows with mastitis (conductivity alarm list or visual inspection of cows) were related to the type of AMS. In this study the mastitis treatment rate during the first year of AMS increased from 0.44 to 0.61 per cow per year, while the time of treatment relative to stage of lactation was unchanged. Furthermore, individual cow somatic cell counts showed small and temporary increase after introduction of AMS. Rasmussen (2004) reported that in tests of five different AMS models in six herds, the sensitivities for the detection of abnormal milk in the six herds varied from 13% to 50% for all milkings, 22% to 100% for the test day milkings, and 43% to 100% when predicting the previous week’s milking. Specificities for the same time periods were 87% to 100%, 85% to 100%, and 35% to 100%, respectively. He concluded that the sensitivities and specificities are generally too low for automatic diversion of abnormal milk and that most of the models could benefit from application of more sophisticated algorithms or measurements more directly related to the ‘gold standard’ used to define of abnormal milk (homogeneity).

While virtually every researcher concluded that sensing systems were inadequate for automatic milk diversion, the quality of milk in these same field studies was generally no different than for conventional cohort farms. While there is evidence of the need for further technological advances, the skill of dairy operators in working with the available tools to meet their milk quality objectives must be applauded!

Conductivity / Impedance

Barth, et al. (2000) reviewed the 40 year history of the development of electrical conductivity (EC) and concluded that although EC is not directly related to udder health or SCC, the ease of measurement has attracted interest and EC become widely adopted. They also indicated that EC of foremilk is a better predictor of health status than milk extracted later while AMS systems usually use the highest EC values during milking. Mein, et al. (2004) state that the value of EC as a mastitis detection tool has been disappointing, primarily because the conductivity of milk is easily influenced by a number of variations. Much of the development and research on EC over the past 5 years has been aimed at improving diagnostic accuracy by accounting for sources of variation in milk conductivity unrelated to udder health.

A detection model using time-series models for two variables (milk yield and electrical conductivity) with parameter values and residual variances that are updated by linear regression after each milking (de Mol and Ouweltjes, 2001), increased the percentage of both true and false positive mastitis events compared with single variable predictors. A quarter conductivity sensing system that controls for non-mastitic variables (Mein, et al. 2004) flagged 45 out of 56 cows with a clinically affected quarter (Sensitivity 80%), but raised a false alarm for 7 out of every 100 cows that were truly negative (Sensitivity 93%). Further improvements were predicted by adjusting threshold values to suit individual herds and individual herd management objectives.

Barth (2004) investigated the influence of a twisted cluster on conductivity readings during lactation and suggested quarter EC might be used for detection of tissue strain caused by the milking machine, as well as for monitoring of mastitis. The results of a study by Norberg, and Korsgaard (2004) indicated that traits reflecting the level, rather than the variation of EC (in particular the IQR) were superior in classifying cows correctly. Ramirez-Garcia, et al., (2004) found that the fouling of the Stainless steel electrodes was negligible over at least 5 days and the sensitivity and selectivity of a method using electrical impedance, pH, temperature, and ClZ concentration were good.

Color, Temperature, Particle Size, Infrared, SCC and other components

The ‘gold standard’ for detection of milk abnormalities, visual inspection of foremilk, is unfortunately very imprecise. Even more variable is the degree of care with which foremilk is examined on commercial dairy farms. This has created much difficulty in applying rules and regulations to AMS that do not present a ‘double standard”. A wide variety of sensors have been investigated to detect milk components that are directly or indirectly related to various milk quality or animal health problems.

Optically based sensing systems are as close to visual inspection as any sensing technology but also present limitations in the sensitivity of detection of some milk abnormalities of interest. Optical methods are widely used to locate teats for unit attachment. Bull, et al. (1996) also assessed the potential for detecting manure on teats using information from a color image. They found that color information could not be used to unambiguously identify manure, but incorporating hue and saturation information provided reasonable agreement with human assessment. Perhaps the greatest success of optical systems for milk sensing has detection of blood in milk. Espada and Vijverberg (2002) described a red/green/blue LED array with algorithms to differentiate differences in the average color in combination with differences in color pattern that showed promise in detecting blood, colostrum and some other milk abnormalities. Whyte, et al. (2004a) described an optical sensor to detect blood in milk with an experimental sensitivity of 100% and specificity of 99.6%.

Larsen, et al. (2004a) analyzed milk clots isolated from mastitis milk for their protein composition and concluded that clot formation was not a result of casein precipitation caused by the elevated proteolytic activity. A sensor system using optical methods to detect clots and flakes in milk developed by Maassen-Francke, et al. (2004) showed very promising results, classifying about 90% of the samples correctly.

Near infra-red (NIR) analysis of milk has been used for mastitis detection as well as composition measurement. Borsboom and Dommerholt (2004) presented some fundamentals of optical metrology of milk making use of rapid developments in electro/optical technology that offer an increasingly wide range of low cost sensing components in the UV-IR wavelength. A study to calibrate NIR sensors for measuring SCC (Tsenkova, et al., 2000) indicated high accuracy of the method. Wiedemann and Wendl (2004) achieved a sensitivity of 55% for a threshold of

200,000 SCC and 71% for a threshold of 500,000 SCC with a specificity of 95% by combining spectral reflectance (SR) of red light (620-700nm) with EC (sensitivity 10% above either method alone) and that measurement of the first fractions of the quarter milk was essential for both methods. Tsenkova, et al. (2004) reported on a method for non-invasive NIR analysis of udder tissue for in-vivo mastitis diagnosis that could be suitable for robot milking where teats' locations are found by optical scanning.

Other technologies have also been developed to measure somatic cells. Whyte, et al. (2004b) described an automated SCC sensor based on measuring the DNA concentration of milk that could be applied to an AMS. DeLaval has also announced the release of a “Direct Cell Counter” to measure SCC at cow-side.

Mottram, et al. (2000) state that use of conductivity sensors is misleading for mastitis detection since they have low sensitivity to some inflammatory responses and do not detect systemic infections unless these also lead to mastitis. They proposed a mastitis sensor based on the detection of elevated levels of the enzyme N-acetyleglucosaminidase (NAGase), released into milk as a result of tissue damage when the cow is resisting a clinical intra-mammary infection. Hamann and Halm (2004) reported that NAGase activity, fat, protein, and lactose showed non-linear patterns dependent on milking interval (MI) and that NAGase and lactose for MI > 10 hours suggested udder inflammation. The authors suggest that due to its insensitivity to MI, lactate could be useful for automatic mastitis detection when the cell count level is < 100,000 cells/ml. A study by Larsen, et al. (2004b) on proteolytic enzymes in milk from cows inoculated with streptococcus uberis indicated that milk quality in the contralateral gland may be compromised.

Cow Behavior, Milk Flow, and Milk Production

A survey of AMS users (De Jong, et al. 2003) reported that many readily available and familiar variables were used by diary managers to detect cows in need of treatment and/or milk diversion. Deviations in daily milk yield (compared to a rolling average for individual cows), and milking interval (time since last successful milking) were reported to have been used as much or more than milk conductivity as a flag for visual inspection of cows. Mottram, et al. (1994) described a method to monitor milk flow as an aid to management in automatic milking systems. Petermann, et al. (2000) studied quarter milk flow profiles and concluded that quarters with a high maximum milk flow had a greater risk of intramammary infection.

Conclusion

A review of the state-of-the-art sensing technology for automatic milking systems (AMS) suggests that while the sensing systems currently being used lack the sensitivity for automated diversion of ‘abnormal’ milk, they do provide sufficient information for motivated dairy producers to achieve milk quality that meets or exceeds national averages. Electrical conductivity and milk color are the most widely used on-line milk sensing methods and deviation in milk yield and milking interval are widely used supporting diagnostic techniques. A number of other methods using visible and other light spectra have shown promise in detecting milk abnormalities and measuring various components of milk. Several methods of measuring the Somatic Cell Count of milk at cow-side have been demonstrated and may be applied to AMS in the near future. Developments in AMS milk sensing systems point toward the use of inputs from a number of sources including milk composition, animal behaviors, and milking characteristics combined and analyzed by centralized ‘smart’ system to improve diagnostic accuracy.

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