Online Detection of Dairy Cow Subclinical Mastitis using Electrical Conductivity Indices of Milk

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Research paper

Online detection of dairy cow subclinical mastitis using electrical conductivity indices of milk

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ABSTRACT

Existing commercial cow mastitis detectors require bulky historical data which may be unavailable or are considered expensive in conventional or small parlours. Thus, the objective of this study is to develop a simple, but without significant sacrifice of accuracy, online cow subclinical mastitis detector for conventional and small parlours. The detective indices are derived merely from the electrical conductivity (EC) of milk using linear discriminant and step regression analyses. The detector was validated on 192 milkings of 48 dairy cows from conventional, small parlours. It had a specificity of 83.7% for healthy quarters, a sensitivity of 46.2% for infected quarters, a prediction accuracy of 90.8% for healthy quarters, and a prediction accuracy of 30.7% for infected quarters. The performance is poorer than commercial detectors, but it is good enough for the dairy industry. This study gives the possibility to give alerts in the milking parlour and no need for animal identification.

1. Introduction

Mastitis is the most common and costly disease in dairy cows since it can reduce milk yield, degrade milk quality, and increase healthcare cost. It is an inflammatory reaction of udder tissue to bacterial, chemical, thermal or mechanical injury. The inflammatory response consists of changes in the constituents in the udder tissue blood and the milk (Sheldrake et al., 1983; Astroshi et al., 1996; Hortet and Seegers, 1998; Leitner et al., 2012). The mastitis leads to an increase in white blood cells (somtatic cells) which eradicate the irritant, repair the damaged tissue, and hence recover the infected udder (Sheldrake et al., 1983). The susceptibility of mastitis infection in a cow can be confirmed through counting the quantity of somatic cells in milk (Mottram, 1997; Malinowski et al., 2006; Kasikci et al., 2012). However, the somatic cell count (SCC) technique cannot provide immediately mastitic information in milking as it requires costly and time-consuming laboratory practice. Online mastitic alert during milking is an essential requirement for automatic milking systems (Mottram, 1997; Hogeveen et al., 2010; Ordolff, 2001; Leitner et al., 2012), based on which, mastitic milk can be isolated from healthy milk to assure quality milk product and it could help in shortening the elapsed time till treatment (Ipema and Hogewerf, 2008). Hence efforts have been devoted to introducing computers and electronics to milking, through which, various milking data are analysed for building an automated subclinical mastitis detection system (Maatje et al., 1997; Mottram, 1997; Kim and Heald, 1999; Shahid et al., 2011).

Besides the increase in the SCC, mastitis increases the concentrations of sodium (Na^+) and chloride (Cl^-) in milk, which lead to a higher electrical conductivity (EC) in the mastitic milk (Kitchen, 1981; Guidry, 1985; Spakauskas et al., 2006; Janzekovic et al., 2009; Kasikci et al., 2012). Furthermore, the body temperature increases as a result of the triggered immune mechanism and the milk yield will be lower because of the abnormal udder tissue. Dairy cows infected with mastitis can hence be identified by proper interpretation of these variables with the EC of milk as the principal parameter (Lake et al., 1992; Maatje et al., 1997; de Mol and Ouweltjes, 2001; Biggadike et al., 2002; Norberg, 2005; Kamphuis et al., 2008; Shahid et al., 2011; Romero et al., 2012). In addition to the identification of visible clinical mastitis, the ability of interpreting these data on line may allow the detection of disease and oestrus at their early stage of development and could help in shortening the elapsed time till treatment (Biggadike et al., 2002;

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Heleili et al., 2012). The data have to be transformed to information that can be used by the farmer, or by a decision support system; though the transformation is complex.

The use of EC in detection of subclinical mastitis in dairy cows has been intensively studied in the past and has gained many applauses from the industry (Ordolff, 2001; Norberg, 2005). The use of time-series models for detection of mastitis based on historical EC of milk, historical milk yield, and variations of temperature could reach nearly 100% of accuracy in both the sensitivity and the specificity (de Mol and Ouweltjes, 2001). It can give alerts in the milking parlour and no need for animal identification. The result is promising, but the service cost may be too high for conventional and small parlours. A less costly scheme for online detection was developed using historical EC measurements of milk in the past 14 days (Biggadike et al., 2002). A positive alert of mastitis is announced if the current EC is 10% exceeding the average of the previous 14-day recordings. However, the performance is sensitive to the selection of the threshold value.

The schemes based on historical data are sometimes considered less practical for conventional and small parlours because of limited professional staff and facilities for collecting historical information and subsequent analysis. A more practical approach is the use of real-time measurements, which is widely adopted by commercially available mastitis detectors, although the accuracy of detection is a bit poorer. The use of the ratio of instantaneous EC to the maximum EC gave a superior performance to the EC mean scheme in mastitis detection, resulting in an accuracy of 80.6% for clinical cases and 45.0% for subclinical cases (Norberg et al., 2004). The performance is obviously inferior to that of using historical information as mentioned previously. However, detection of subclinical mastitis infection based on instantaneous measurements rather than on historical information is more affordable for conventional or small parlours.

Our laboratory developed a computerised EC measurement system suitable for study into the correlation between EC and mastitis infection (Lien et al., 2005). The system can be incorporated as part of an automatic milking system to acquire EC and temperature of milk during milking in real time. To improve the system for better performance of mastitis identification using short-length EC recordings, this paper uses linear discriminant and step regression analyses to infer an optimum combination of various EC indices from a bulking number of variables. The objective is to realise a EC-based mastitis detector suitable for conventional or small palours.

2. Materials and methods

2.1. Data recording in milking

Fig. 1 (a) shows the online EC measurement system (Lien et al., 2005) used in this study. The milking claw (Fig. 1(b)) is embedded with 4 EC electrodes and a resistive temperature detector (RTD), This design supports simultaneously 4 individual quarter EC measurements and temperature measurement of the collected milk during milking. A teat cup will detach away autonomously in response to a shrinking udder because of insufficient milk.

The EC electrodes were calibrated using a 5.00 mS/cm NaCl solution. The measurements are conditioned and processed with a microprocessor-controlled quarter milk conductivity (QMC) meter developed in house. The QMC meter processes EC measurements with temperature compensation based on temperature measurement from the RTD. The system can process eight QMC meters for eight dairy cows at the same time. Data from the QMC meters are transmitted to the host computer via the RS485/RS232 data converter (ADAM-4520, Advantech, Taiwan). The computer runs a data acquisition program which was developed using the Visual Basic programming language in the Windows platform. Both EC and temperature recordings are saved on the computer for subsequently off-line analysis.

The participant dairy farm had a herd of 120 Holstein cows. This size scale is quite common in Taiwan. No cow had visible clinical mastitis symptoms. Forty eight (48) cows and therefore 192 quarters were randomly selected from the herd. The milking process was performed using the system of Fig. 1(a) twice a day, from 5:00 h and 16:00 h. Foremilk (30 ml) before every machine milking was taken manually for mastitis examination using a somatic cell analyser (Fossomatic 300, Foss Electric, Denmark). The two batches of data from the same cow were discarded if they had significantly different SCC values. The two milks with significantly different SCC's means that the cow has healthy status changed in the same day. Morning recordings were used as an analysis group for deriving detective indices while afternoon recordings as a validating group. A dairy cow was marked as mastitis-infected (positive alert) if one of its quarter milkings has an SCC beyond 500,000 cells/ml (Nielen et al., 1995; de Mol and Ouweltjes, 2001).

2.2. Selection of detective EC indices

2.2.1. EC in the early stage of infection

One of the largest advantages of using the EC of milk in detection of dairy cow mastitis is the possibility of daily recording and its availability during the period when the cow is infected (Norberg, 2005). Hence, EC and derived indices are normally used for detection of mastitis by most EC-based mastitis detection systems (Ordolff, 2001). Most cases of mastitis appear in early lactation, particularly in the first 50 days (Lund et al., 1999). Thus, EC information of the first part of lactation is a good indicator of mastitis detection.

Detection of mastitis based on instantaneous EC measurements is simple and efficient, but it may be considered less reliable as a clear-cut EC between healthy and infected milks should be available *a priori* (Biggadike et al., 2002). The foremilk of an infected quarter milking contains abundant somatic cells and active ions than following milk. Hence an infected quarter milking shows high SCC and EC values at the start of the milking. There exists a maximum EC in a milking and it is denoted as EC_{max} in this paper.

A cow is unlikely to have all the four quarters infected in the early stage of mastitis infection and an infected quarter has therefore an EC apparently higher than the others (Woolford et al., 1998). This fact elicits the inclusion of the EC ratio between an infected and a healthy quarters to improve the reliability of mastitis detection. An EC ratio (ECR) is defined as a ratio of the maximum EC to the minimum EC among the four quarters in a milking, as:

$$ECR = \max(EC_k)/\min(EC_k) \quad (1)$$

with k symbolized as LF for left-front, LR for left-rear, RF for right-front, and RR for right-rear quarter.

2.2.2. EC moving average for improvement of reliability

The probability of having an EC recording during the period when the cow is infected is near unity (Norberg, 2005), and valuable information about the subclinical mastitis status of the cow is obtainable at every milking. An EC sensor that picks EC of flowing milk may not have consistent reliability and repeatability (Ordolff, 2001). For example, sensitivity of electrodes may vary about 4% of average conductivity (Rossing et al., 1987). Moving averages turned out to be most suitable to account for measurement uncertainties caused by, for example, quarterwise sensor variation and movement artefacts by the cow.

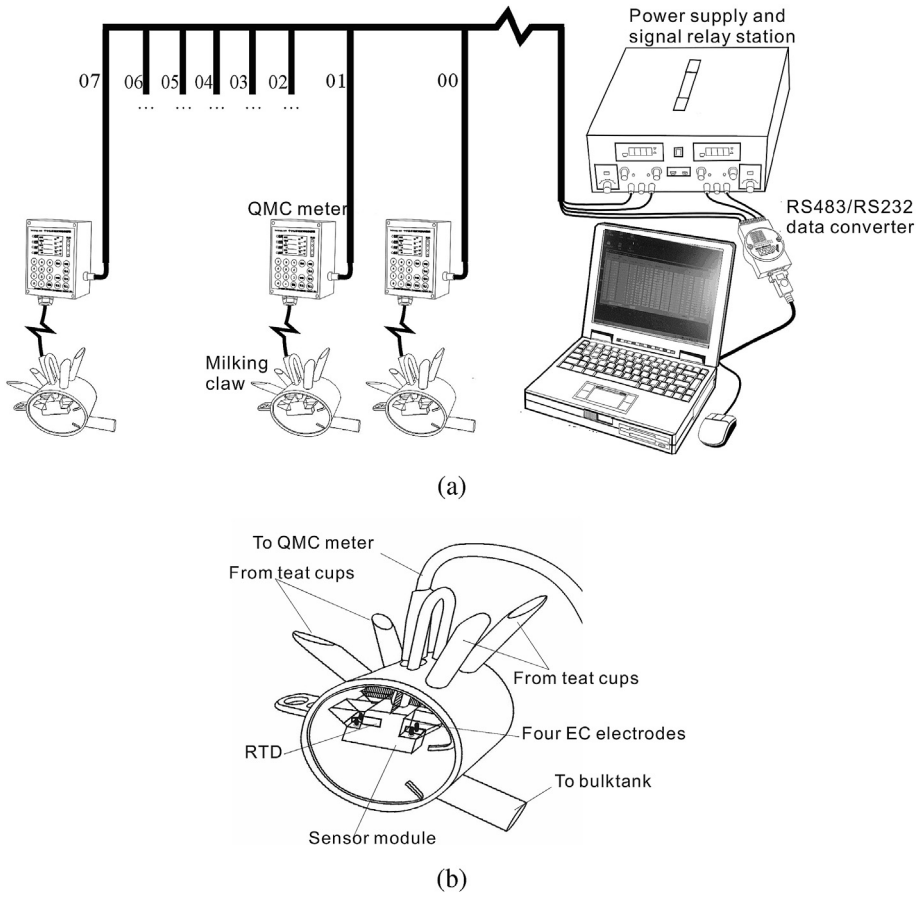

Fig. 1. (a) The online EC measurement system. (b) The milking claw.

Fig. 2 is an example EC recording marked with defined EC variables, EC_t or ECR_t for respective EC or ECR measurement at time stamp t and EC_{t1-t2} and ECR_{t1-t2} as moving averages of respective EC and ECR between time stamps t_1 and t_2. The moving average of a quarter is calculated by:

$$EC_{t1-t2} = \sum_{t=t1}^{t2} EC_t/(t_2 - t_1) \quad (2)$$

for EC, and

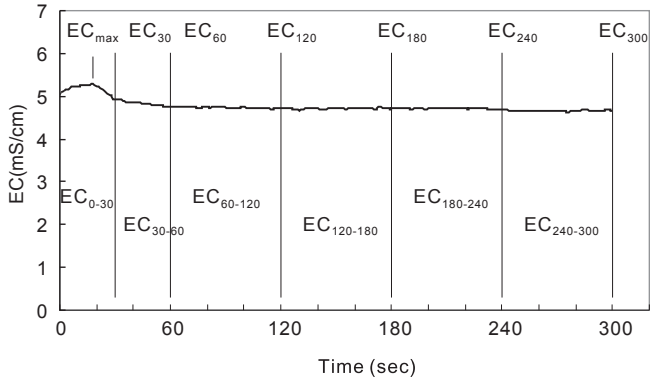

Fig. 2. Instantaneous and segmental EC recordings for analysis.

$$ECR_{t1-t2} = \sum_{t=t1}^{t2} ECR_t/(t_2 - t_1) \quad (3)$$

for ECR.

2.3. Assessment of prediction performance

The model outcomes are compared with actual occurrences of subclinical mastitis detected with the SCC method. A mastitis case identified using EC is marked as true positive (*TP*) if it is confirmed by SCC, otherwise a false negative (*FN*) case. The number of *FN* and *TP* cases was used to calculate the sensitivity, as: (*TP*/(*TP*+*FN*)) ×100%.

A milking from a healthy cow without a mastitis alert using EC was classified as true negative (*TN*); it was false positive (*FP*) if an alert by EC occurs. The number of the *TN* and *FP* was used to calculate the specificity (EC negative test result/disease is not present), defined as the percentage of *TN* milkings: (*TN*/(*TN*+*FP*)) ×100%.

Table 1 summarises the assessing scheme. The accuracy of detection is defined as the percentage of *TP* and *TN* cases: (*TN*+*TP*)/(*TN*+*FP*+*FN*+*TP*)×100.

2.4. Statistical analysis

2.4.1. Suitability of detective indices

The correlation of an EC variable to mastitis infection was described using the SAS General Linear Model (GLM) procedure.

Table 1
Criteria for assessing the performance of mastitis detection.

Using EC	Using SCC		Quantity	Predictability (%)
	Healthy	Infected		
Healthy	*TN*	*FN*	*TN*+*FN*	*TN*/(*TN*+*FN*)
Infected	*FP*	*TP*	*FP*+*TP*	*TP*/(*FP*+*TP*)
Total	*TN*+*FP*	*FN*+*TP*	*TN*+*FP*+*FN*+*TP*	
Sensitivity (%)		*TP*/(*FN*+*TP*)		
Specificity (%)	*TN*/(*TN*+*FP*)			
Accuracy (%)	(*TN*+*TP*)/(*TN*+*FP*+*FN*+*TP*)			

The designated apparent significance level was set to α=0.05. The least square method of the GLM procedure is applicable for groups without identical sample counts. The Scheffé test was used to compare the significance of each variable between health and infection.

2.4.2. Linear discriminant analysis

Linear discriminant analysis (LDA) is a statistical technique to classify individuals or objects into mutually exclusive and exhaustive groups on the basis of a set of independent variables. In this study, LDA is used to find an optimum linear combination of EC variables that minimises the probability of misclassifying milkings into their respective statues. The variables used in computing the linear discriminant functions were chosen in stepwise regression, both forward and backward, using the SAS STEPDISC procedure. At each step, the variable that adds most to the separation of the classes is entered into (forward) or the variable that adds least is removed from (backward) the discriminant function. The SAS DISCRIM procedure was used to perform discriminant analysis for classifying the quarters into healthy and infected classes.

3. Results and discussion

3.1. Example EC recording

Milking information, sampled every 1 s by the system of Fig. 1, includes the time of milking, cow number, QMC number, quarter EC and ECR, and temperature of milk. Fig. 3 presents example EC and ECR recordings from a healthy dairy cow with all the four quarter SCCs less than 200,000 cells/ml (Nielen et al., 1995). Fig. 4 shows an infected case with the SCC of the LF quarter higher than 4,800,000 cells/ml and the others less than 200,000 cells/ml, i.e. the cow had an infected LF quarter.

The healthy cow, in Fig. 3, had almost four overlapped quarter EC recordings and a nearly flat ECR profile. In contrast, the mastitic cow of Fig. 4 had an higher EC contour in the LF quarter than in the other quarters, in the early stage of milking. This mastitic behaviour becomes more obvious in the ECR profile of Fig. 4(b).

3.2. Suitability of EC indices

3.2.1. Instantaneous EC

Table 2 summarises the result of variance analysis on instantaneous EC measurements from the 192 quarters. The Scheffé test shows that there are significant differences between EC_{max} and EC_{30} and between EC_{20} and EC_{60}. The others are considered redundant in status distinguishing. Hence we need to deal with EC measurement every 30 s in mastitis detection.

Table 3 shows an example of variance analysis on the above inferred detective variables, in which the teat cups detached autonomously because of insufficient milk supply as a result long-time milking. The coefficients of variance after EC_{180} are much larger than the others. Hence ECs after EC_{180} were discarded from

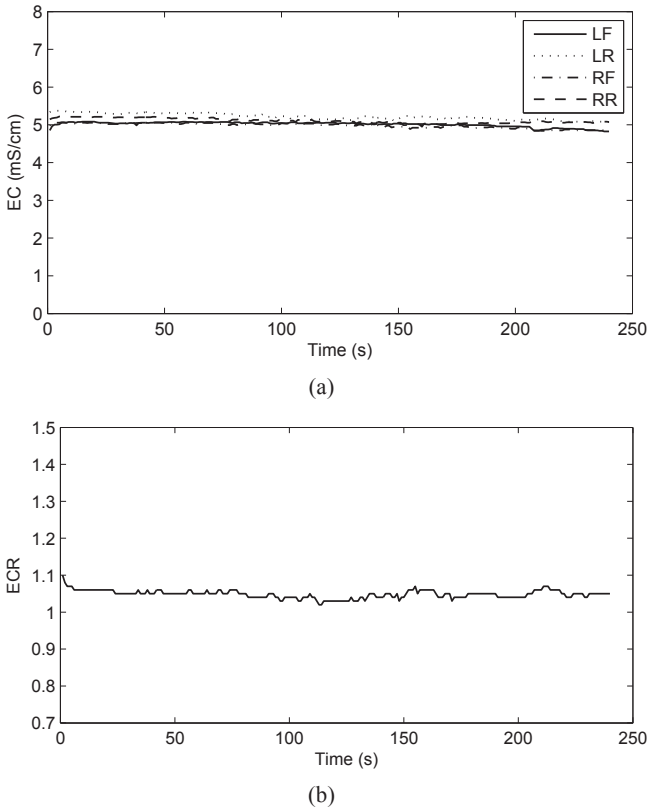

Fig. 3. Time responses of (a) EC and (b) ECR from an uninfected dairy cow.

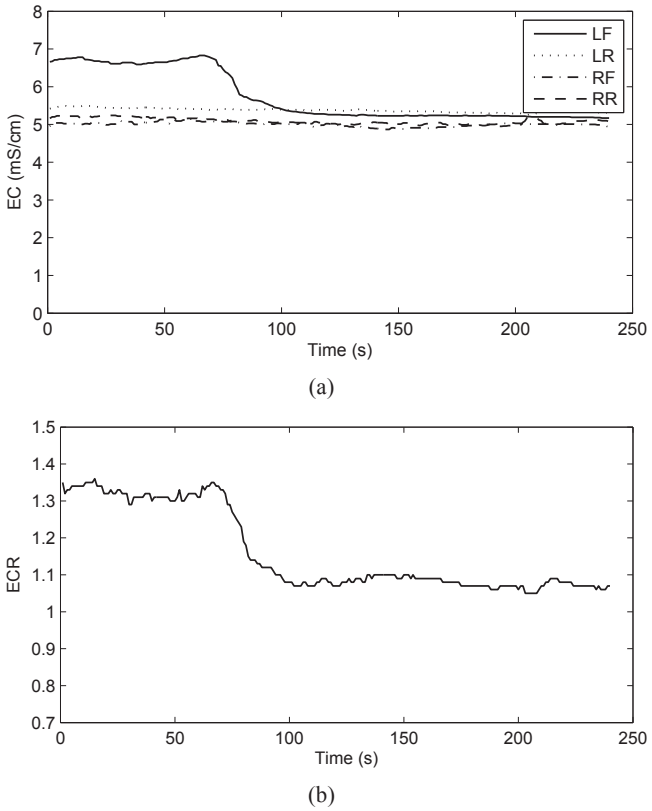

Fig. 4. Time responses of (a) EC and (b) ECR from a dairy cow with an infected LF quarter.

Table 2
Significance of instantaneous EC measurements on detection of mastitis.

EC	Mean	S.D.*
EC_{max}	5.39	0.67^{a}
EC_{10}	5.23	0.50^{ab}
EC_{20}	5.19	0.45^{ab}
EC_{30}	5.14	0.85^{bc}
EC_{40}	4.92	0.89^{c}
EC_{50}	4.90	0.68^{c}
EC_{60}	4.90	0.57^{c}

*At the same column, values with different superscripts are significantly different ($P \leq 0.05$) in means by the Scheffé test.

Table 3
Significance of selected EC measurements on mastitis detection.

EC	Mean ± S.D.*	C.V.**
EC_{max}	5.39 ± 0.67^{a}	0.124
EC_{30}	5.14 ± 0.85^{b}	0.165
EC_{60}	4.90 ± 0.57^{bc}	0.116
EC_{120}	4.79 ± 0.74^{bc}	0.156
EC_{180}	4.57 ± 1.07^{cd}	0.234
EC_{240}	4.25 ± 1.39^{d}	0.327
EC_{300}	3.63 ± 1.81^{c}	0.499

*Values with different superscripts are significantly different ($P \leq 0.05$) in means by the Scheffé test.
**Coefficient of variance, C.V. = S.D./Mean.

analysis to eliminate the possibility of insufficient milk supply from a quarter. The significance of EC_{max} arises from the accumulated somatic cells and active ions in the milk prior to milking. In summary, the Scheffé test suggests the use of instantaneous EC_{max}, EC_{30}, and EC_{120} as detective indices.

The 192 quarter milkings were categorised to a healthy (166 samples) and an infected (26 samples) groups based on the SCC thresholding criterion. As shown in Table 4, the Scheffé test on the two groups shows that EC_{max} and EC_{30} are significantly different in distinguishing the two statuses. EC_{30} is, in fact, a recording of foremilk which contains abundant active ions, as Fig. 4 reveals. To aggregate the effect of EC_{30} and EC_{120}, a differential variable is defined as:

$$\Delta EC = EC_{30} - EC_{120} \quad (4)$$

This equation signifies the difference of the EC between foremilk and succeeding milk.

3.2.2. EC moving average

Table 5 lists the result of Scheffé's test on EC moving averages. The Scheffé test indicates that both EC_{0-30} and EC_{30-60} have the same effect on mastitis detection. Either can be used as a detective index. This fact is unveiled by the plateau of the LF ECR profile presented in Fig. 4. Thus, a differential variable is defined to account for the EC difference between foremilk and succeeding milk, as:

Table 4
Detection of mastitis using ECs.

	Healthy	Infected
Samples	166	26
EC_{max}	5.20 ± 0.60^{a1}	5.68 ± 0.73^{a2}
EC_{30}	5.06 ± 0.58^{ab1}	5.50 ± 0.71^{ab2}
EC_{60}	4.91 ± 0.45^{bc1}	5.06 ± 0.57^{bc1}
EC_{120}	4.81 ± 0.45^{c1}	4.77 ± 0.92^{c1}

Values are in mean± SD. At the same column or row, values with different superscripts (alphabet for column and digit for row) are significantly different ($P \leq 0.05$) in means by the Scheffé test.

Table 5
Detection of mastitis using EC moving averages.

	Healthy	Infected
Samples	166	26
EC_{0-30}	5.04 ± 0.58^{a1}	5.47 ± 0.70^{a2}
EC_{30-60}	4.99 ± 0.51^{ab1}	5.26 ± 0.56^{ab2}
EC_{60-120}	4.83 ± 0.44^{bc1}	4.92 ± 0.64^{b1}
$EC_{120-180}$	4.74 ± 0.64^{c1}	4.86 ± 0.63^{b1}

Values are in mean± SD. At the same column or row, values with different superscripts (alphabet for column and digit for row) are significantly different ($P \leq 0.05$) in means by the Scheffé test.

$$\Delta ECm = EC_{30-60} - EC_{120-180} \quad (5)$$

3.2.3. Instantaneous ECR

As shown in Table 6, the Scheffé test on the analysis group shows that ECR_{30} and ECR_{120} are most important in identifying the status of infection. To have a best use of ECR, a differential variable is defined to account for the gap between ECR_{30} and ECR_{120}, as:

$$\Delta ECR = ECR_{30} - ECR_{120} \quad (6)$$

3.2.4. ECR moving averages

Table 7 lists the result of Scheffé's test on ECR moving averages. Healthy and infected udders can be identified using ECR. However, all ECR segments almost have the same specificity of infection identification. To have a best use of ECR averages, a differential variable is defined to account for the gap between ECR_{30-60} and $ECR_{120-180}$, as:

$$\Delta ECRm = ECR_{30-60} - ECR_{120-180} \quad (7)$$

3.2.5. Detective indices

In summary, the analysis suggests that EC_{max}, ΔEC, EC_{0-30}, ΔECm, ECR_{30}, ΔECR, ECR_{0-30}, and $\Delta ECRm$ can be used as detective indices for identification of mastitis infection.

3.3. Performance of mastitis detection

3.3.1. Individual indices

The previous section shows that EC_{max} is most effective among all detective indices. Table 8 lists the performance of using EC_{max} as the sole detective index. The specificity of healthy quarters is 69.9%, the sensitivity of infected quarters 65.4%, the predictability of healthy quarters 92.8%, and the predictability of infected quarters 25.4%. The accuracy of detection using EC_{max} is 69.3%. This accuracy is considered too poor to be acceptable.

Results of identifying the analysis group using all detective indices are summarised in Table 9. ΔEC has the most effective specificity, the best accuracy of detection and also most effective in identification of healthy quarters, but EC_{max} is most sensitive in

Table 6
Detection of mastitis using ECR.

	Healthy	Infected
Samples	28	20
ECR_{30}	1.079 ± 0.071^{a1}	1.148 ± 0.132^{a2}
ECR_{60}	1.050 ± 0.041^{b1}	1.076 ± 0.067^{b1}
ECR_{120}	1.061 ± 0.051^{b1}	1.097 ± 0.075^{ab2}

Values are in mean± SD. At the same column or row, values with different superscripts (alphabet for column and digit for row) are significantly different ($P \leq 0.05$) in means by the Scheffé test.

Table 7
Detection of mastitis using ECR moving averages.

	Healthy	Infected
Samples	28	20
ECR_{0-30}	1.078 ± 0.070^{a1}	1.145 ± 0.136^{a2}
ECR_{30-60}	1.066 ± 0.058^{ab1}	1.118 ± 0.087^{a2}
ECR_{60-120}	1.058 ± 0.041^{b1}	1.088 ± 0.058^{a2}
$ECR_{120-180}$	1.062 ± 0.042^{ab1}	1.097 ± 0.056^{a2}

Values are in mean± SD. At the same column or row, values with different superscripts (alphabet for column and digit for row) are significantly different ($P\leq0.05$) in means by the Scheffé test.

Table 8
Performance of mastitis detection using.EC_{max}

Using EC_{max}	Using SCC		Total	Predictability (%)
	Healthy	Infected		
Healthy	116	9	125	92.8 (116/125)
Infected	50	17	67	25.4 (17/67)
Total	166	26	192	
Sensitivity (%)		65.4 (17/26)		
Specificity (%)	69.9 (116/166)			
Accuracy (%)	69.3 (133/192)			

identification of infected quarters. Discriminant analysis is hence conducted to find the most dominating indices.

3.3.2. Improvement of prediction accuracy

Stepwise regression analysis of all detective indices suggests that Δ*EC*, ECR_{0-30}, and Δ*ECRm* are the most dominating indices, with statistics summarised in Table 10. Δ*EC* possesses the largest partial R-square and *F* values. This means that Δ*EC* is the most discriminating index among the three indices. This analytical result matches the results summarised in Table 9.

The three most dominating indices listed in Table 10 were applied to identifying the analysis group with results listed in Table 11. The performance of using the three most dominating indices is a bit better than the sole use of Δ*EC*. The accuracy of detection is improved from 79.2% to 80.2%. The reliability of the three dominating indices were validated by testing on the validating group. Table 12 presents the result. The accuracy of detection is 78.6%. The performance is promising in comparison with the work (Biggadike et al., 2002), in which, historical data of the previous 14 days were used. The performance of the previous work has a specificity between 85 and 92%, a sensitivity between 40 and 54%, a predictability between 87 and 93% for healthy quarters, and a predictability between 33 and 55% for infected quarters.

4. Conclusions

Counting the number of somatic cells in milk indicates directly the susceptibility of mastitis infection in a cow. This technique requires costly, labourious laboratory practice. Measuring the EC in milk gives an alternative approach. Traditionally, using only EC for mastitis detection is less accurate than the use of a combination of EC and other information (de Mol and Ouweltjes, 2001; Kamphuis et al., 2008). However, sole use of EC information deserves the simplicity and economy in equipment construction. The analytical framework proposed in this paper is very helpful in working out the most dominating EC indices. The framework was used to examine a small parlour with 120 cows, among which, 48 cows were randomly selected for study. None had visible mastitis symptoms. The indices were inferred from an analysis group of 192 quarter milkings and were validated on another 192 quarter milkings from the same 48 dairy cows. The validation demonstrated a specificity of 83.7%, a sensitivity of 46.2%, a predictability of 90.8% for healthy quarters, and a predictability of 30.7% for infected quarters. The 90.8% of healthy quarter predictability is a bit inferior to the 86.5% (166/192) of actual healthy percentage by the SCC technique. However, this proposed framework allows the realisation of a

Table 10
Statistics of the three most significant EC indices by stepwise regression analysis.

EC	Partial R-square	*F* value	*Pro.>F*
Δ*EC*	0.1084	23.35	0.0001
ECR_{0-30}	0.0211	4.08	0.0448
Δ*ECRm*	0.0213	4.09	0.0446

Table 11
Application of the three most dominating indices Δ*EC*, ECR_{0-30}, and Δ*ECRm* to the analysis group.

EC response	Status of origin		Total	Predictability
	Healthy	Infected		
Healthy	142	14	156	91.0
Infected	24	12	36	33.3
Total	166	26	192	
Sensitivity		46.2		
Specificity	85.5			
Accuracy	80.2			

Table 12
Validating result of the three most dominating indices.

EC response	Status of origin		Total	Predictability
	Healthy	Infected		
Healthy	139	14	153	90.8
Infected	27	12	39	30.7
Total	166	26	192	
Sensitivity		46.2		
Specificity	83.7			
Accuracy	78.6			

Table 9
Comparison of identification performance using various indices.

Using EC	Using SCC		Specificity	Sensitivity	Predictability		Accuracy
	Healthy	Infected			Healthy	Infected	
EC_{max}			69.9	65.4	92.8	25.4	69.3
Δ*EC*			84.3	46.2	90.9	31.6	79.2
EC_{0-30}			63.9	57.7	90.6	20.0	63.0
Δ*ECm*	166	26	77.1	46.2	90.1	24.0	72.9
ECR_{30}			80.1	42.3	89.9	25.0	75.0
Δ*ECR*			77.7	42.3	89.6	22.9	72.9
ECR_{0-30}			82.5	42.3	90.1	27.5	76.6
Δ*ECRm*			75.3	42.3	89.3	21.2	70.8

simple and economic mastitis detector to provide real-time detection result without the use of historical EC recordings.

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