IOT SMART ADD-ON FOR SMALL-FARM MILKING MACHINE

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Abstract. The goal of this research was to create a novel solution for in-flow milk control, automated alerting, and IoT data collection that can be implemented cost-efficiently on small farms to replace manual sample control with portable devices. The offered solution can control milk in-flow, working with any small size milking machine, to provide three main indicators: overmilking phase alert, milk temperature, subclinical mastitis probability indicator, and it has the capability for data collection. We developed a prototype using off-the-shelf available IoT technology, tested it on the farm with a portable milking machine, and verified the results with manual detector data. The test results demonstrated that the designed prototype provided reliable overmilking phase detection, reproducible milk temperature readings, and the subclinical mastitis condition diagnostic data were consistent with Draminski manual detector data.

Keywords: IoT sensors, subclinical mastitis, cow milking.

Introduction

Subclinical mastitis condition detection is a topic of research last years due to its very complex nature. A survey arranged by [1] in 2019 aiming to identify research priorities regarding the use of sensors to improve productivity and sustainability on dairy farms revealed that more than 12% of respondents named mastitis as an area, where more research is required. Fundamentally different detection methods are discussed in the literature and used in practice [2]. Most works published on different aspects of mastitis detection are concentrated on issues actual for big farms, discussing requirements to such detection systems [3; 4], sensor system application to monitoring cow health [5] and different detection technologies [2; 6; 7]. In many cases, complex and expensive methods of acquiring data are employed to investigate the correlation between different environmental factors, measured milk parameters, and the herd health conditions, including mastitis.

To make the solution feasible, even for big farms with sufficient resources, subclinical mastitis alerting devices should balance two factors: cost of solution and efficiency of alerts. For small farms, this balance is even more important, therefore, a different approach to technology is required to achieve a cost-efficiency balance in this sector. A trade-off for the cost of resources is also actual for Latvian dairy farms taking into account that almost 77% of farms have from 3 to 19 cows. The number of farms with the corresponding livestock is shown in Table 1 [8].

Table 1

Number of farms with the corresponding number of dairy cows at the end of 2019

Number of dairy cows in the farm	**3-5**	**6-9**	**10-19**	**20-29**	**30-49**	**50-99**	**100-199**	**200-299**	**≥ 300**	**300-499**	**≥ 500**
Number of farms	1916	1322	1222	390	361	283	126	37	50	30	20

IoT technology for data collection and alerting is increasingly used on large-size dairy farms in automated milking systems offered by major manufacturers. Small farms typically use smaller and cheaper equipment, which still lacks IoT functionality, so manual detectors are usually used on small farms instead of in-flow milk control. Since IoT technology is becoming ubiquitous, we decided to implement cost-efficiently in-flow milk control, automated alerting and IoT data collection on small farms instead of manual sample control with portable devices and to provide additional benefits of data collection for analyses.

Taking into account small farm specifics, the device should control milk in-flow, work with any small size milking machine, provide three main indicators: overmilking phase alert, milk temperature, subclinical mastitis probability indicator, and it should have the capability for data collection. At the same time, a typical function in a big farm’s milking equipment, i.e., milk volume metering, is not crucial for small equipment.

The novelty of our solution is based on the ability to control milk in-flow, working with any small size milking machine, provide three main indicators: overmilking phase alert, milk temperature, subclinical mastitis probability indicator, furthermore, it has the capability for data collection. We observed multiple researches aiming to develop a portable device to monitor the health status based on the threshold value of electrical conductivity (EC) [9]. However, we have not found similar research on the solution for control milk in-flow working with any small size milking machine.

Materials and methods

We set our goal to build a low-cost IoT add-on, which could be used with any milking machine, could replace manual detectors, provide small dairy farms with in-flow milk control and simple alerts, and ensure extensive historical data analyses capability in the future. As a majority of researchers [2], we focussed on methods based on milk electrical conductivity (EC) measurements, mainly because it is reported to be efficient enough, and it is convenient for in-flow implementation.

The designed prototype consisted of an IoT module for data processing, display, radio module, mounted on the tube in-flow sensors module with probes and power supply modules, shown in Fig.1. To achieve the goal of efficient and cost-effective implementation, the data processing module used off-the-shelf Arduino UNO v. 2 with ATMEL microprocessor, fitted with liquid crystal display, and RF-69 radio module (868 MHz). Arduino IDE Open Source software was used for prototype programming. The microprocessor board has multiple digital and analogue-to-digital converter (ADC) inputs, which we used for EC measurements and to receive digital signals from temperature, and flow sensors. Measurement results are shown on display, alerts are provided by a 3-color light-emitting diode (LED) and a small buzzer.

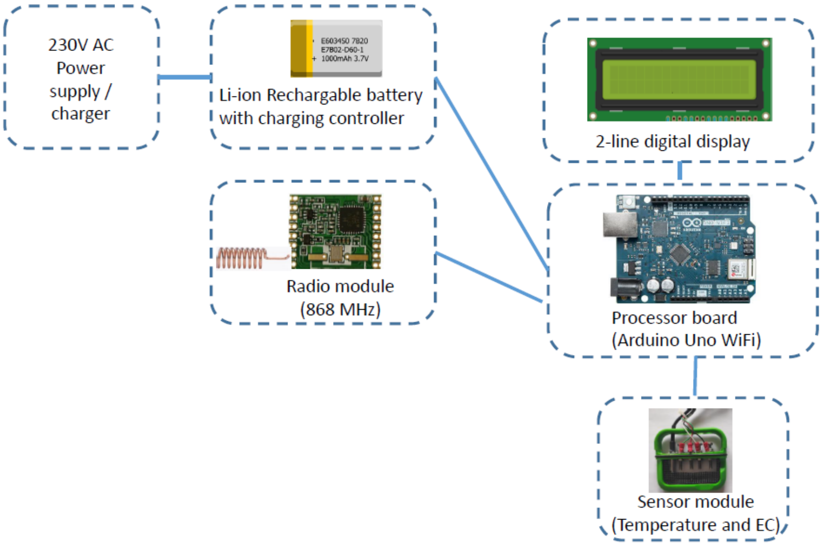

Fig. 1. **Flowchart of IoT based prototype**

An in-flow measurement cell was made adding 3 probes (two for EC measuring and one for temperature measuring) to the standard industrial milk filter housing. This makes the designed prototype compatible with any milking machine. To avoid probe corrosion or oxidation, we used stainless steel probes for EC measurement and a temperature sensor in a stainless steel tube. No surface degradation was observed during testing.

We tested two different methods for overmilking stage detection: traditional milk flow measurements and conductivity measurements. For flow detection, we initially used a turbine flow meter with impulse output, when the milk flow drops in the overmilking faze, the impulse frequency diminishes. This approach is typical for big dairy farm equipment, which usually includes high precision flow meters to measure milk input. We found that EC measurements, performed for mastitis detection can be used for reliable overmilking phase-detection because of the significant and easy detectable conductivity drop.

Testing demonstrated that both methods provide reliable overmilking stage detection, but the flow meter is much more cumbersome to clean and maintain, and the decision was made to use conductivity measurement in the prototype. An additional benefit of the EC method is that it is realized in software and does not require any additional components or sensors, which simplified the prototype design.

Milk temperature measurements were implemented to control that EC measurements are made at the same temperature, but any deviations from normal (average) milk temperature can be considered as an indication of some illness. For temperature measurements, we used a standard waterproof DS18b20 temperature sensor in a stainless steel tube. This standard off-shelf temperature sensor that provides highly reproducible digital temperature data with up to 12-bit resolution is factory calibrated with metrological uncertainty under 0.5 °C. Similar sensors are available with uncertainty under 0.1 °C or better, but such precision was unnecessary for our goal. The temperature sensor was connected to the processor board using the standard digital one-wire interface. Fig. 2 presents a milking machine Armiks used for IoT prototype testing and a sensor module.

Fig. 2. **Small milking machine used for IoT prototype (on left) and a sensor module (on right)**

However, as depicted in [7], and [2], multiple factors affect the milk EC, including the month of lactation, mineral content, fat content, somatic cell count (SCC), etc. Significant variations of correlation between EC, SCC, and other factors are observed in different cow populations, which proved that there is no simple threshold value that can be used to flag subclinical mastitis conditions for any cow. At the same time, data correlation for the same cow is much easier to analyse, as most mentioned factors are stable, therefore, changes in EC because of subclinical mastitis are easier to detect and interpret reliably. This approach is typical for simple, un-integrated mastitis detection tools, for example, DRAMINSKI Mastitis Detector 4Q, when daily data get tracked and analysed for each cow separately and manually. When the average value is known for each cow, the alert is generated not so much from the measured EC value itself, but an unexpected significant change of defined value.

When measuring liquid EC, usually resistance between 2 probes is measured, and an absolute value of conductivity can be derived from this measurement using the probe geometry data and calibration by using etalon fluids with known conductivity. For our goal, detecting the change of EC, an absolute value of EC is irrelevant, as far as the same probes are used for all measurements, and absolute calibration is not required. At the same time, the temperature has a big impact on the milk EC value, and we used an in-flow temperature sensor to control that analysed EC values are measured at similar temperatures.

EC measurement resolution threshold in our prototype was limited by the ADC scale 10 bit, but as expected, the range of milk conductivity values is in fact narrow – just 3-10 mS [7], such resolution was sufficient for our goal. The actual measured and displayed value depends on the measurement cell geometry and measurement circuit parameters, so the measured values can be directly compared only between identical (or identically calibrated) setups.

To evaluate prototype capability to provide preclinical mastitis alerts, we tested milk using prototype and commercially available Draminski mastitis detector 4Q. This manual detector displays values, which are proportional to milk resistance between 2 stainless steel probes. It means that as higher conductivity is displayed, as lower is a reading (lower resistivity). Draminski detector is not calibrated to show the milk electrical resistivity (ER) absolute value and does not convert resistivity into conductivity value, as it is not necessary for the intended use. Following the manual, values for different cows are expected to be slightly different, therefore, a subclinical mastitis indicator is used not as a value itself, but as a substantial resistivity drop from a typical (average) reading for a particular cow. For easier data comparison, we programmed our prototype in a similar way to the Draminski detector, i.e. to display milk ER in relative units.

Results and discussion

Preliminary testing was conducted to prove the device prototype concept, feasibility of the technical solution and to validate its functions, before moving to the next stage – manufacturing multiple prototypes and conducting big scale and long period field testing. The prototype was tested using a milking machine from Armiks Ltd. (Latvia). We collected in-flow data from 14 cows on the same farm within fifteen days, milk samples were tested using DRAMINSKI Mastitis Detector, as well as analysed in the laboratory for CSS concentration.

As the milk EC is highly dependent on temperature, it was important to compare data measured at the same temperature. EC tests of milk samples at temperatures in the range + 10 to + 40 ºC, demonstrated that EC grows substantially with temperature, with the rate of about 2% per 1 ºC. Fortunately, in-flow prototype testing demonstrated a very reproducible milk temperature during the milking process (it was 39 ºC, and variations were less than 0.5 ºC). The flow rate was 4-5 l·min^{-1}.

Resistivity measurement data demonstrated such behaviour:

- EC value measured during the testing period was stable (data fluctuation for each healthy cow was under 5%);
- average EC value variations for different cows existed, but for all healthy cows they were under 15%;
- the measured value for the fourteenth cow demonstrated an observable drop of about 40% from the second week.

Fig. 3 demonstrates daily milk ER in relative units' data for 14 cows from the same dairy farm measured by the prototype (horizontal axis shows the number of days: total 15 days).

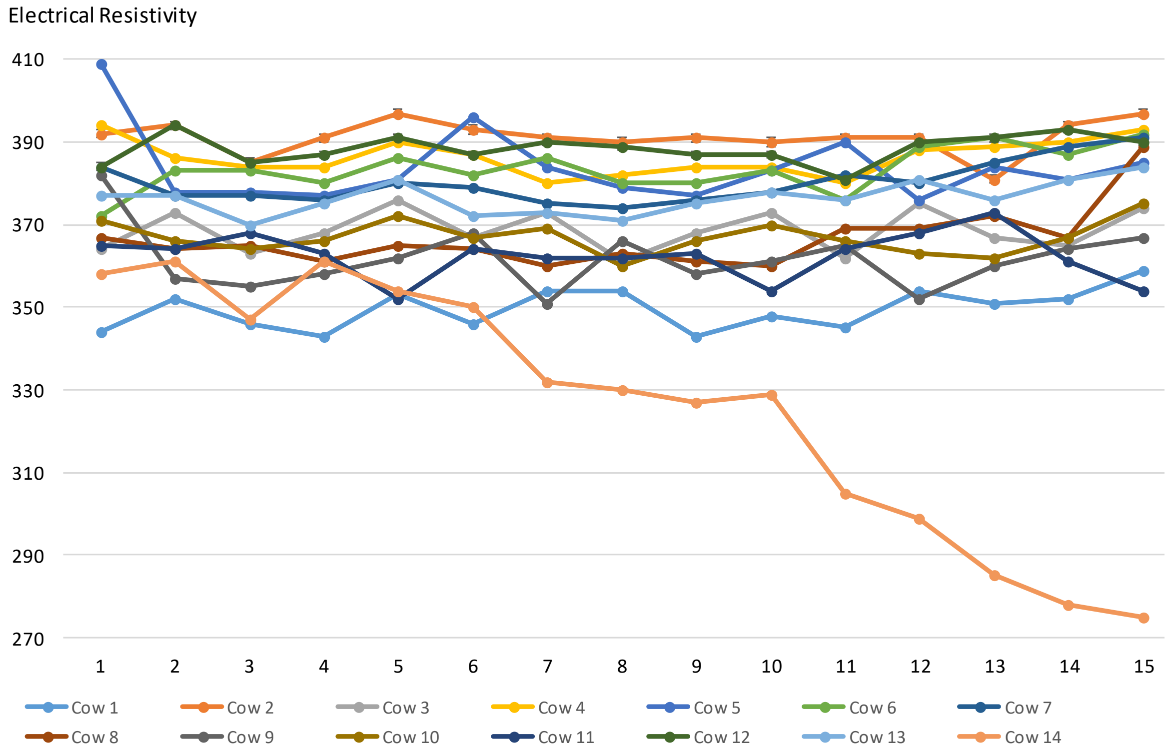

Fig. 3. **Daily milk resistivity data for 14 cows from the same dairy farm (15 day period)**

Fig. 4 shows an example of data correlation between the prototype data and the Draminski Mastitis Detector 4Q of milk sample ER measurements for a cow number 14. It was noticed that absolute values of measurements are different for our prototype and the Draminski Mastitis Detector, but there is a good correlation among them. The difference in absolute values can be attributed to the difference in the measurement cell geometry and measurement circuit parameters. The difference could be excluded by calibrating both devices to show EC absolute values, but there is no real need to do so. As a goal of EC measurements in the prototype is to detect conductivity change (resistivity drop), the absolute value is an irrelevant parameter, since dependence on the cell geometry is always constant. Data analyses showed that readings of the prototype and the Draminski detector are proportional (deviation is less than 1.5%).

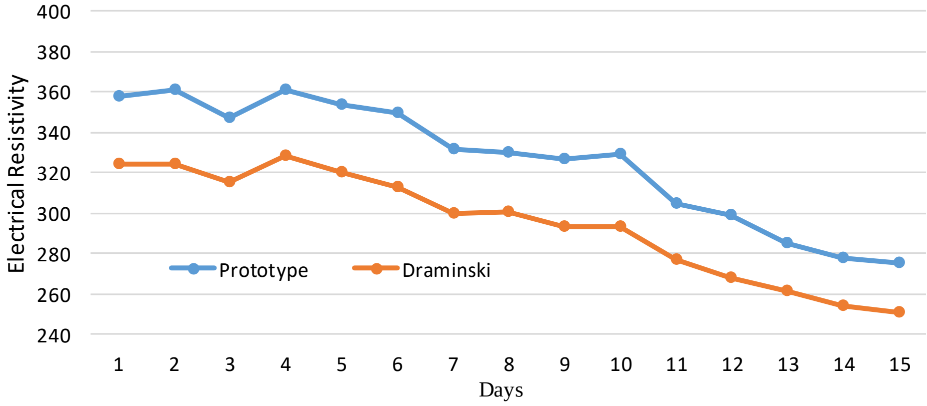

Fig. 4. **Prototype and Draminski Mastitis Detector data correlation for cow No.14 during 15 days**

A significant change in EC about 40%, which we attributed to the early stage of subclinical mastitis, was observed for a cow number 14. As Fig. 3 shows, this deviation is well outside of typically observed measurement uncertainty and is easy to detect. Laboratory tests for SCC demonstrated that the 14th cow had a higher CSS count (250 thousand), when all other cows had CSS lower than 100 thousand.

We compared the ER measurement results obtained by the prototype and by the Draminski detector for 15 days and 14 cows. Our target was to evaluate, how much measurements implemented by the prototype are consistent to the measurements made by the Draminski detector. We calculated a coefficient $K_{consit\ cow \cdot day^{-1}}$ for each of 14 cows during 15 days by dividing ER_{prot} measured by the prototype to $ER_{Draminsk}$ measured by the Draminski detector. The results were recorded in a table, which is not published in this paper due to the lack of space, and then the average value of $K_{consit\ cow}$ (Mean) was published in Table 2 (see columns 1 and 2).

Table 2

Comparison of ER measurement results obtained by the prototype and by Draminski detector

Cow No	Mean	St.d.	Conf. T	Interval	
Cow 1	0.8978	0.004598	0.002546	0.8952	0.9003
Cow 2	0.8981	0.003670	0.002032	0.8961	0.9001
Cow 3	0.9002	0.005377	0.002978	0.8972	0.9032
Cow 4	0.9008	0.003308	0.001832	0.8990	0.9026
Cow 5	0.9008	0.003098	0.001716	0.8991	0.9025
Cow 6	0.8993	0.003796	0.002102	0.8972	0.9014
Cow 7	0.8985	0.003243	0.001796	0.8967	0.9002
Cow 8	0.8992	0.005077	0.002811	0.8964	0.9020
Cow 9	0.8998	0.004639	0.002569	0.8972	0.9023
Cow 10	0.8995	0.004517	0.002502	0.8970	0.9020
Cow 11	0.9007	0.003740	0.002071	0.8986	0.9028
Cow 12	0.9004	0.003907	0.002163	0.8983	0.9026
Cow 13	0.8999	0.003692	0.002045	0.8979	0.9020
Cow 14	0.9037	0.007634	0.004228	0.8994	0.9079

In order to evaluate the results of our research we applied the t distribution (Student's t-distribution), which is used to estimate population parameters, when the sample size is small and when the population variance is unknown. The t distribution provides a good way to perform one sample tests on the mean, when the population variance is not known. Additionally, the t distribution provides good results, when the population is not normal and even when the sample is small, provided the sample data are reasonably symmetrically distributed about the sample mean.

We calculated a standard deviation and also the confidence interval for the t distribution as CONFIDENCE.T(α, s, n), where n = sample size (15), s = sample standard deviation and 1 – α is the confidence%. For example, for a Cow 1: Mean 0.8978, St.d 0.004598 CONFIDENCE.T = 0.002546, which yields a 95% confidence interval of the sample mean is (0.8952 0.9003) (see Table 2).

The analysis of the results in Table 2 revels that the measurements implemented by the prototype are consistent to the measurements made by the Draminski detector, thus, the measurement precision supports our assumption.

We tested measurement data transmission by the radio-module to the Internet gateway (Cloud Gateway device from E-meter Ltd.) and found that very reliable data transmission was achieved on distances up to 200 m from the receiver in a real farm environment. Future use of this function will require software development for received data collection and processing. Test results confirmed that the designed prototype functions correspond to the planned ones, and the measurement results correlate well with the data from commercially available manual mastitis detector. The prototype provides the benefit of in-flow automated measurements and automated data collection possibilities.

We are aware that EC on its own is not a very precise method for detecting mastitis [10]; [11], however, its accuracy can be improved by combining with other detection methods. Therefore, more extensive research is planned after multiple prototype manufacturing on the next stage to develop extensive data sets for longer periods involving more tested cows. Data will be analysed in correlation with different factors to provide valuable insights, to determine mastitis alert error rate, and possibly improve the reliability of them. For example, the temperature sensor data were used just to confirm that EC data were measured at the same temperature, however, the temperature data have a large potential. As the temperature sensor is stable and has good resolution, it could be possible to make long-term analyses of cow milk temperature deviations and obtain valuable information from these data changes of cow body temperature. The radio transmitter module provided convenient remote data collection capability for data long-term analyses. It will find extensive use in the future, when an application for data collection from each milking cow on the farm for a lifetime will be implemented.

The data analysis has the potential not only to improve alert precision, but to provide additional valuable insights. In the future, additional sensors can be added to the IoT device, so even more data can be collected and processed. It looks like an attractive option in the future to use a mobile phone as a data receiver and gateway to a cloud (processor board has a WiFi module, which can be used for this purpose), so data can be displayed and analysed on a smartphone, as well as transmitted over a mobile network to cloud for storage and deep AI (Artificial Intelligence) analyses.

Conclusions

1. A working prototype of an IoT add-on to a small milking machine was designed to provide overmilking alerts, temperature, and subclinical mastitis monitoring in-flow, as well as data collection capability.
2. Reliable detection of the overmilking phase was achieved, using EC measurements without any moving parts.
3. Temperature measurements demonstrated very reproducible readings and have the potential to detect cow body temperature anomalies.
4. Subclinical mastitis detection based on electrical resistivity (ER) demonstrated a good correlation with the Draminski mastitis detector 4Q data.
5. Reliable measurement data transmission on distances up to 200 m was demonstrated.
6. The prototype was found to function as expected and can be recommended for commercial manufacturing. More extensive tests are planned, which will improve alerting precision, as well as provide additional health data.

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