Supervision of physical, chemical and electric variables in milk refrigeration

Vitoria B. Santana, Wesley M. A. da Silva, Manoel A. Cordeiro Neto and Geronimo A. Barbosa

Abstract: This paper summarizes the main results of the design and implementation of a low-cost multi-parameter meter focused on the supervision of milk quality. The quality meter is associated to a smart energy meter. The proposed system can measure and store the collected data and also has a remote monitoring system. This low-cost network can be used by farmers and milk producers in order to keep up with milk quality parameters, such as PH and temperature, along with their energy consumption behavior. The paper illustrates the hardware architecture, discusses the adopted communication protocol solutions and is completed with the product validation experiment.

***Index Terms* — data supervision, electronic instrumentation, low cost, prototype.**

I. INTRODUCTION[1]

THE dairy industry is an important branch of the Brazilian farming industry. Milk represents 24% of the gross value added of agricultural crops and animal production, hunting and related service activities [1]. In order to use the milk properly, the producers and industries must comply with a series of rules and regulations imposed by Embrapa, the Brazilian Agricultural Research Corporation. One of these rules states that the milk must be reduced to a temperature of 4ºC (39.2ºF) within two hours after the milking, which forces producers to use a refrigeration system to control milk temperature [2].

Before the popularization of the milk cooling tanks, producers would store the milk in 10 L (338.14 oz.) or 50 L (1690.7 oz.) cans (the so-called “milk-cow”) that could not prevent the milk from going acidic and losing its quality and usability. Nevertheless, there is still much to be improved and reshaped in the dairy supply chain.

The Southern region of the State of Pernambuco is the biggest dairy basin of the state, which puts Pernambuco in the eight places in the national ranking of milk production. In fact, in 2016 the milk produced in the state amounted to 893,029,000 liters [2].

The city of Aguas Belas produces approximately 45,692,000 liters each year, ranking fourth in dairy production in the state. The dairy industry plays an important role in the economy of more than 20 cities, and there are more than 106,000 local producers in total. One of the most common problems related by local producers is the lack of an equipment or system that would allow them to keep track of all (or at least more than one at once) milk quality parameters.

Another challenging problem that received substantial interest is related to the energy consumption behavior of their cooling tanks: the producers were also in need of a technology that would not only measure but also control their tanks in terms of electricity consumption.

Therefore, this paper aims to present a new technology developed in order to help milk producers in the storage and refrigeration of milk: a multi-parameter meter that can measure the physical, chemical and electrical variables of the milk in the cooling tank in real time.

Although it was initially focused on producers from the region of Aguas Belas in Pernambuco, the system can be easily replicated in any other region. The development and implementation of new technologies in milk refrigeration bring economic gain for the producers and guarantee the quality of the product.

II. METHODS AND PROCEDURES

This research can be divided in two phases: the theoretical phase and the experimental one. Initially, in the theoretical phase, survey data regarding the main difficulties in milk production were collected from local farmers/milk producers. The answers included:

(1) The quality of the milk produced, sold and bought is directly affected by the lack of technologies that would allow a real-time analysis of physical and chemical properties of the milk? This would not only guarantee the quality of the product across the entire value chain, but also would prevent milk waste, which happens to be a very common practice in the sector. The literature review found that 45% of technical losses in dairy products occur during storage and cooling [3].

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(2) The data collection revealed that the milk tanks also happen to be a cause of milk waste in local farms. According to MAPA, the Ministry of Agriculture, Livestock and Supply of Brazil, milk can be harmlessly stored in tanks for three hours after milking [4].

In case the tank is damaged, malfunctioning or nonfunctional, the milk will probably spoil early, and therefore farmers will be forced to dump all the content in the tanks since they are no longer able to sell their product.

This waste could be prevented by implanting a system that would allow farmers to keep track of the energy consumption of each tank. Farmers would be alerted early about a possible malfunction because there would be noticeable changes in the energy consumption pattern of the malfunctioning tank.

The sufficiently accurate solution to solve the addressed problems is the development of a multi-parameter meter what would not only be used to analyze physical/chemical properties of the milk but also electrical properties of the tanks the milk is stored in. After a short literature review, the development of prototype began with simulations in specialized software, such as Fritzing, Quickcad and Proteus and the Arduino platform.

After this stage, a list of materials to be used in the prototype was prepared, and it is presented in Table 1.

TABLE I. PROJECT BUDGET.

Equipment	Quantity	Price
5V source	1	15.90 BRL (3.15 USD)
LCD Display LCD	2	27.90 BRL (5.53 USD)
Protoboard	2	11,60 BRL (2.30 USD)
ESP32	1	60.00 BRL (11.68 USD)
Pressure sensor	1	75.00 BRL (14.85 USD)
pH sensor	1	64.13 BRL (12.70 USD)
Ultrasonic sensor	1	17.22 BRL (3.41 USD)
Temperature sensor	1	15.21 BRL (3.01 USD)
Current sensor	1	48.90 BRL (9.68 USD)
TOTAL: 335.86 BRL (66.52 USD)		

Initially, the microcontroller chosen was the Arduino Uno R3 board, but it did not meet the project's needs due to their limited number of ports. Thus, the Arduino MEGA 2560 board was chosen due to its large number of digital inputs and outputs. However, this microcontroller still presented limitations such as the lack of Bluetooth and Wi-Fi connection on a single hardware.

Therefore, the ESP32 (Espressif Devkit ESP-WROOM-32 V1.0) was chosen as the project's final microcontroller: not only it provides a large number of available ports, it also makes wireless connection possible (through both Wi-Fi and Bluetooth). This microcontroller proved to be a very useful tool to solve the problems that motivated the project. It can be programmed through the Arduino IDE, making it possible to customize the project.

Subsequently, the prototype was assembled. It was subjected to tests and thus underwent some changes and adaptions, and so did the code previously assemble.

Fig. 1 shows the schematic connection of the current sensor to the microcontroller, while Fig. 2 shows the electrical diagram of the physical-chemical variables meter assembly.

Fig. 1. Electrical diagram of the milk quality meter.

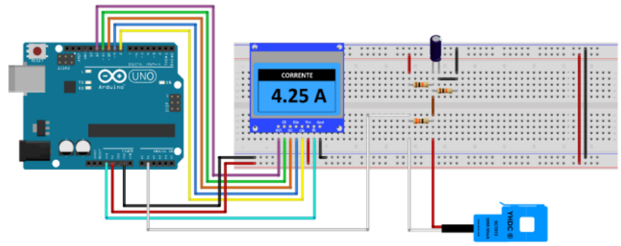
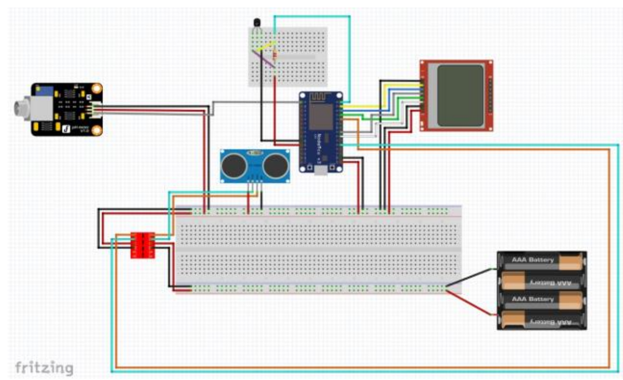


Fig. 2. Electrical diagram of the milk physical-chemical variables meter.



The smart meter proposed for checking the quality of milk has three operational stations, namely: supervision station (mobile application and Channel ThingSpeak), measurement station (sensors installed in the cooling tank) and execution station (ESP32 microcontroller).

In Fig. 3 illustrates the prototype mounted on a protoboard for the calibration tests of the temperature, pH, tank volume and active energy sensors consumed by the refrigeration equipment.

Fig. 3. Meter of physical-chemical variables.

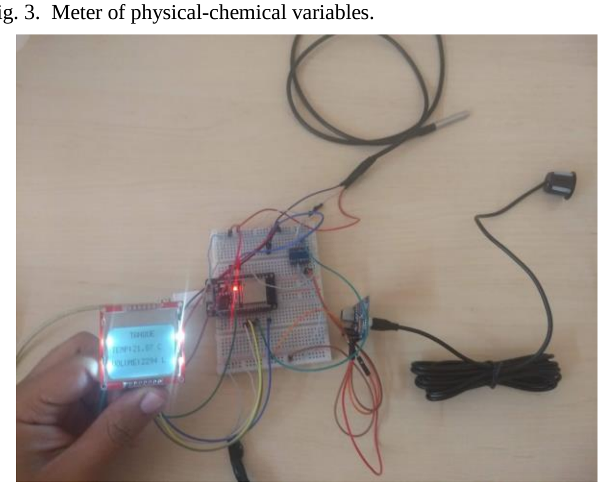


Fig. 4 and 5 show the results of the sensor calibration measurements in laboratory.

The final prototype was also calibrated and validated in the laboratory, then it was finally installed and in the 1.000 Liter tanks provided by local farmers: the Marcos Rogerio Rocha Malta Farm and the Belo Dairy (all located in Aguas Belas in the state of Pernambuco).

Fig. 4. Physics-chemical measurements.

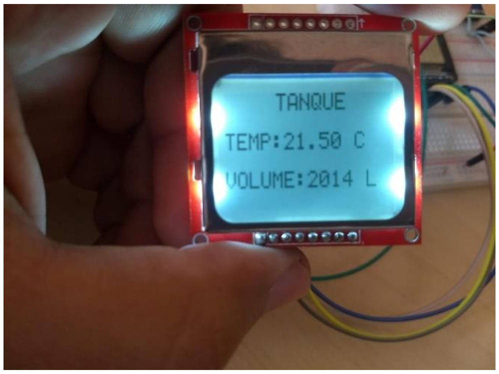
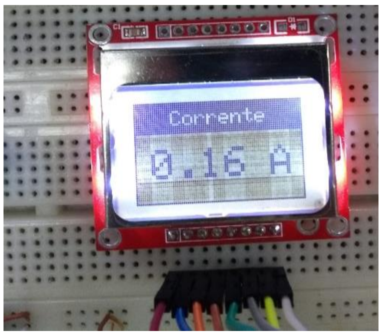


Fig. 5. Electric current measurement.



The remote monitoring system was developed using the online platform ThingSpeak, an IoT (Internet of Things) analysis platform that allows the aggregation, visualization and analysis of data streams in a very simple way. Its communication protocol is based on MQTT for sending data generated on ESP32, Arduino or any other device with resources for network communication.

One of its advantages of its use is the possibility of visualizing the data sent by the devices in real time, and also the availability of MATLAB for a deeper analysis. MATLAB is a high-performance interactive software of numerical calculation.

The remote monitoring interface was complemented by the development of a Bluetooth application for monitoring via cell phone.

The proposed prototype can be compared to two other products available in the national market:

(1) The draminski mastitis detector (3255 BRL – 622 USD): This product can detect mastitis through measuring the milk impedance. It does not include a database or a real-time monitoring interface.

(2) ITPH3500 of the INSTRUTEMP (3328 BRL – 636 USD): This equipment is used to measure and store pH, conductivity, salinity and oxygen levels. It can be used not only in milk, but also in water, ethanol and water-based solutions. The database of this system is created through a data logging program.

The main differences between these systems and the proposed prototype are: none of the products currently available in the market include an online database nor a Bluetooth application for remote supervision.

Both the products shown are battery-powered, while the proposed system can operate from a battery pack or an external power source. Another important difference is that none of the products measure the milk volume inside the tank.

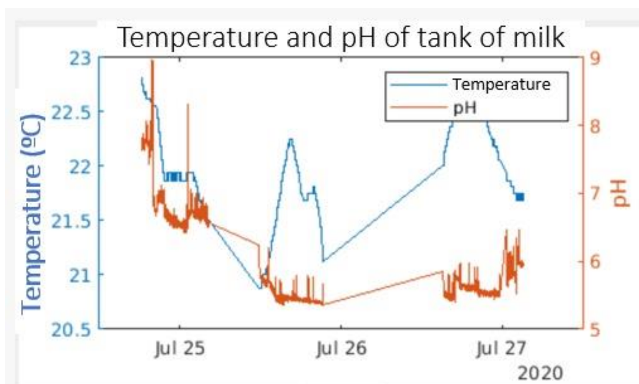
Regarding the experimental comparison between the ITPH3500 and the assembled prototype, the proposed meter showed more precision in the pH measurements and a greater operational range in the temperature measurements. The tests were performed in a DXOSB tank with capacity of 1.000 Liters.

III. RESULTS AND DISCUSSION

The material used to assemble the prototype added up to a total value of 335.86 BRL (approximately 66 USD), which confirms the possibility of creating a smart energy meter and a multi-parameter meter at a low price, when compared to the technologies currently available in the market. For instance, the AEOTEC Energy Meter Samsung costs an average of 350.00 BRL (approximately 69 USD).

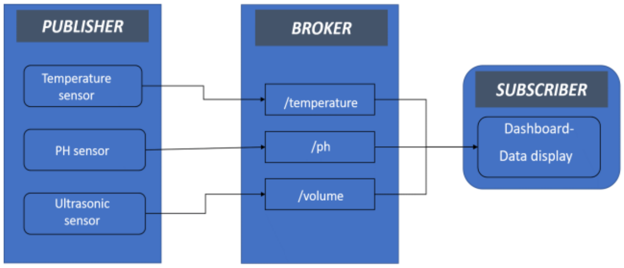
Fig. 6 shows an overview of the ThingSpeak channel, which receives the data from the sensors and displays them in the platform interface.

Fig. 6. Internet monitoring screen.



The graphs are generated in the following way: the sensors send data obtained via digital or analog signal to the microcontroller. The microcontroller, then, processes the data according to the source code and then sends the now processed data via MQTT protocol to the ThingSpeak channel.

Fig. 7. Diagram of the operation of the MQTT protocol.



The data flowchart for the cloud using MQTT protocol is illustrated in Fig. 7, the project publisher will be the ESP32 microcontroller that will send data from all sensors, the ThingSpeak platform will play the role of Broker and anyone who accesses the available channel the system will be Subscriber.

The comparative results between the proposed intelligent meter and meter ITPH3500 of the INSTRUTEMP is illustrated in Table II.

TABLE II. COMPARISON BETWEEN THE ITPH350 AND THE PROPOSED METER.

Parameter	ITPH3500	Proposed meter
Temperature	± 0.5ºC	± 0.5ºC
pH	± 0.1	± 0.04
Dissolved oxygen	± 3% + 1 digit	-
Conductivity	±1% + 1 digit	-
Salinity	±1% + 1 digit	-
Volume	-	1.000 Liter

The efficiency of the system can be proved by comparing the sensors measurements shown in Fig. 6 to the acidity and Ph measurements found in the literature review [6].The Table 3 shows the pH and the acidity measure (expressed in Dornic degrees), 1 Dornic degree (1°D) is equal to 0.1g of lactic acid per liter. These measurements make it possible to control the quality of raw milk.

TABLE III. DATA OF THE PH AND ACIDITY FOR RAW MILK.

pH	Acidity (ºD)	Interpretation
6.6 – 6.8	15 – 18	Fresh milk
≥ 6.9	< 15	Alkaline milk/Adulteration with water
6.5 – 6.6	19 – 20	Slightly acid milk/Fermentation process partially started
6.4	± 20	Degradation after heating the milk to 110º C (230ºF)
6.3	22	Degradation after heating the milk to 100ºC (212ºF)
6.1	≥ 24	Degradation during pasteurization
5.2	55 – 60	Spoiling at room temperature
6.5	9 – 13	Whey

The ThingSpeak platform is configured to be updated in 5 seconds to 5, with 144 daily measurements. In addition to data storage, the raw milk quality meter, has local supervision via computer, through of the PLX-DAQ tool, is plotted the data measured in MS Excel.

IV. CONCLUSION

The prototype presented low cost when compared to similar commercial product, reliable data and accuracy in measurements; being a didactic tool to support learning in the teaching of undergraduate Electrical Engineering. When compared to the current available commercial models, the designed prototype revealed equivalent precision and robustness.

The future research could continue to explore the need for technologies reported by local farmers, in order to develop and integrate more sensors in our prototype. A failure detection system is also an issue for future research to explore.

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