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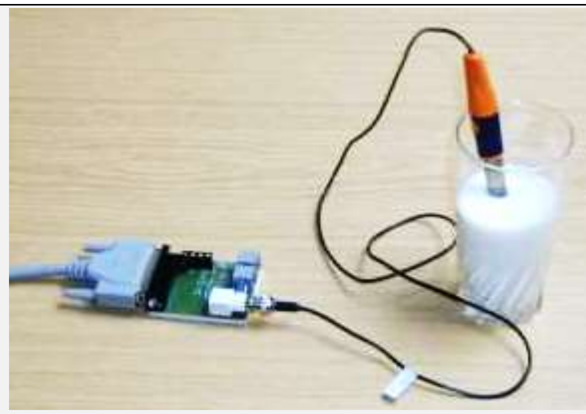

"IoT based milk business optimized monitoring in Rwanda"

'A cow's milk is wealth and health'

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College of Science and Technology

School of African Center of Excellence in Internet of Things

MSc in Internet of Things – Wireless Intelligent Sensors Networks

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UNIVERSITY of RWANDA

Research and Postgraduate Studies (RPGS) Unit

ACEIoT

Thesis Title:

"IoT based milk business optimized monitoring in Rwanda"
'A cow's milk is wealth and health'

By

Deny Beny KAMUHANDA
Ref: 217292887

A dissertation submitted in partial fulfilment of the requirements for the Degree of MSc in Internet of Things
With specialization in Wireless Intelligent Sensors Networks

In the College of Science and Technology

Supervisor: **Dr. Damien HANYURWIMFURA**

Co-Supervisor: **Dr. Philibert NSENGIYUMVA**

Submission date: May 2021

DECLARATION

I, Deny Beny KAMUHANDA, declare that the current research project entitled "IoT based milk business optimized monitoring, Rwanda" is my original research project based on the research and implementation of its prototype. All resources have been quoted in references.

Deny-Beny KAMUHANDA

BONAFIDE CERTIFICATE

This is to certify that the project work, entitled "IoT based milk business optimized monitoring, Rwanda", is a record of the original work done by **Mr. Deny Beny KAMUHANDA (Reference number: 217292887)** in partial fulfilment of the requirement for the award of masters of sciences in Internet of Things in in African Center of Excellence in Internet of Things, College of Science and Technology, University of Rwanda, Academic year 2018-2020.

This work has been submitted under the guidance of Dr Damien HANYURWIMFURA and Dr. Philibert NSENGIYUMVA

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Deny-Beny KAMUHANDA

ABSTRACT

Like in many countries, the government of Rwanda opted a policy to transform the increase of milk production into a business opportunity through its chained production, transportation, transformation and trading, by establishing Milk Collection Centers (MCC), Dairy industries as well as Milk Trading Zones and hence benefited many traders while contributing to the economic development of the country.

However, there is no centralized real-time monitoring of both quality and quantity data, which result in loss at one side or another. As the consumption increases, per agent, the demand increases to the side of industry which results in waiting (queue) of the supply to milk traders. This delaying, not only slows down the businesses, but also, may lead to shortages of milk on the side of the consumers while there is excess of milk on the side of the farmers. Then, some farmers look for alternative solutions, to avoid the wastage, including selling milk to traders directly without dairy involvement, which becomes difficult to ensure the quality of consumed milk especially in case of high local demand.

The integration of internet of things (IoT) devices, such as sensors and microcontrollers, in the existing infrastructures, like tanks, will centralize the real-time monitoring and information sharing of both quantity and quality of milk between traders and suppliers. This will reduce the economic loss and facilitated the food and standard institution to remotely verify the purity of milk being sold to consumers by traders.

The proposed solution, comprising the perception devices, wireless communication technologies and data visualization combined, will help the milk supplier to know when and where to carry milk in real-time, which avoids milk scarcity to traders. Once the milk is diluted or adulterated, the IoT de-vice will notify the institution in charge of quality standards through the browser interface. For sampling purpose, only one IoT device is prototyped.

At the end, when the milk is consumed qualitatively and quantitatively, the profitability on both sides of businesses and farmers will increase, while ensuring the health of consumers, particularly to 38% [1] chronic malnutrition to children in Rwanda.

KEY WORDS

Internet of Things (IoT), Milk level, Milk quality, Milk traders, Ultrasonic Sensor, PH Sensor, Arduino Microcontroller, GSM/GPRS Module,

LIST OF ABBREVIATIONS AND ACRONYMS

ACEIoT: African Center of Excellence in Internet of Things

API: Application Programming Interface

BS; Base Station

CST: College of Science and Technology

FAO: Food and Agriculture Organization

FDA: Food and Drug Authority

GDP: Gross Domestic Product

GPRS: General Packet Radio Services

GSM: Global System for Mobile communication

HTTP: Hyper-Text Transfer Protocol

IDE: Integrated Development Environment

IoT: Internet of Things

MCC: Milk Collection Center

MS: Mobile Station

NST: National Strategic Plan

PH: Power of Hydrogen

RBS: Rwanda Bureau of standards

RFID: Radio Frequency Identification

SDG: Sustainable Development Goals

UR: University of Rwanda

WISeNet: Wireless Intelligent Sensor Networks

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

Chapter 1: GENERAL INTRODUCTION

1.1. Introduction

In Rwandan culture, a cow means wealth and welfare to the family that owns it. Within that same spirit, the government of Rwanda initiated “gira inka”, a program for poor families to own cows that, in addition to providing nutritious food, become a source of income not only to farmers but also to traders whose job is to buy and sell milk to thousands of customers. Many farmers understood and exploited this opportunity, from which the establishment of four dairy industries [1] and 132 Milk Collection Center (MCC) [1] , as highlighted in Figure 1, took place to center the transformation and development of that farming sector hence creating many jobs and contributing to the development of the country, where the growth of dairy GDP is expected to 53% [2] in 2022 equivalent to 2.2 billion [2] liters of milk from 6% [3] in 2017.

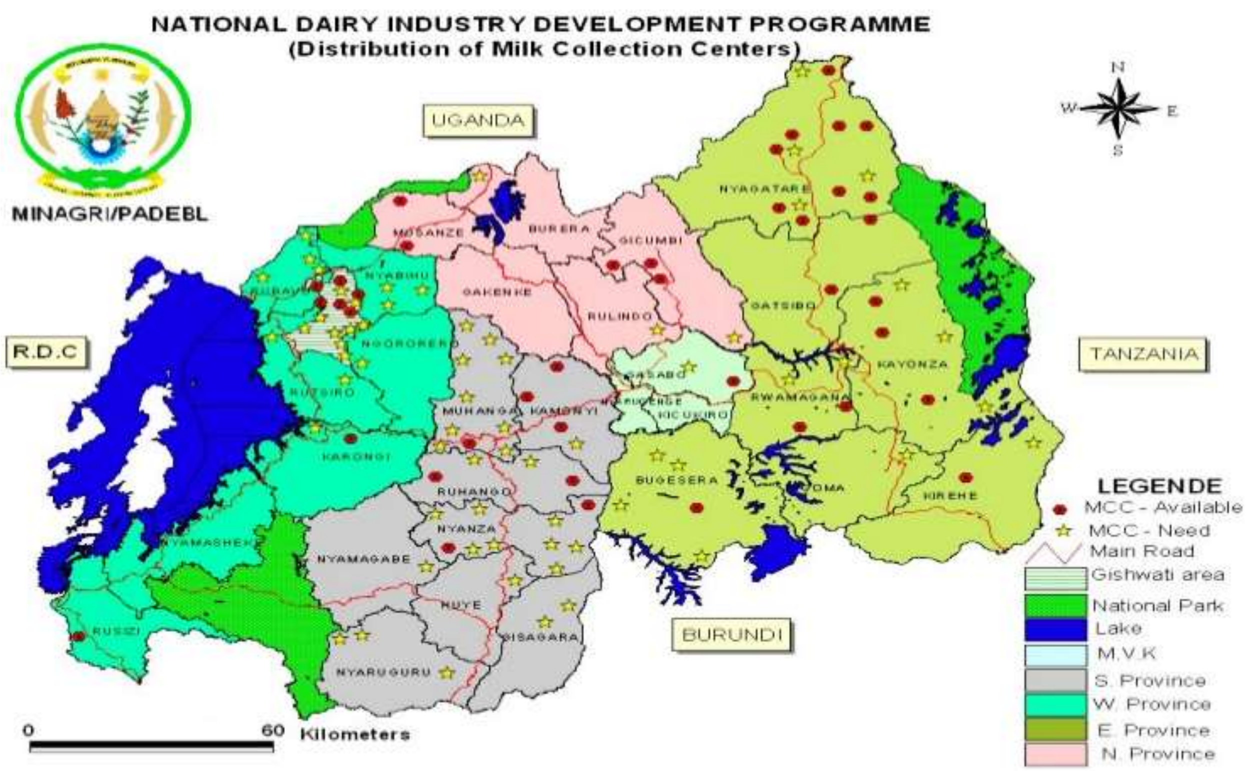


Figure 1: Milk Collection Centers are established countrywide [Inyange Ltd, 2016]

From the traditional milk commercialization to modern industrialization, the information sharing is key important to assure the profitable activity while avoiding the wastage of produced milk and the financial loss of milk traders. The dairies fail to assure, in real-time monitoring, either the quantity and quality of collected or sold milk to consumers via their agents.

As the demand increases, the farmers who are not working with industries sell their milk directly to other traders without dairy's involvement. This raises the concerns of quality issues, which require the periodic, remote, monitoring to assure the healthier milk. Among the impacts are the high percentage rate of malnutrition among children yet the production is said to be increasing for the all-in-one nutritious milk.

According to FAO website [4]; the quality of raw milk refers to its normal composition and acidity without any other substance (debris, flavors, chemicals) added in it and with normal composition and acidity [4].

In 2017, the organization called Land O'Lakes International made an impact report [5] of the program implemented from 2012 to 2017, which shows that the milk production collected and marketed increased from 40 farmers producing 16.1 million [5] liters to 77 farmers producing 48.4 million [5] liters of milk. Because of increased market access of small farmers, farm-level milk sales increased from $4.6 million in 2012 to $66 million in 2016 [5]. In 2018, the Rwanda Agriculture Board estimated the production of milk at more than 816,000 metric tons of milk, an increment of 114.9% [6] with respect to the previous census due to transformation of traditional livestock into lactating cattle, while according to Rwanda Broadcasting agency, the milk production was around two millions of liters in 2019 (RBA news, May 2020).

Every day, farmers transport milk in well cleaned stainless-steel milk-pot to Milk Collection Centers (MCC) (Figure 1) closer to them for being tested, cooled, stored and sold to all milk traders scattered countrywide. They make basic quality tests and then put in appropriate cooling tank while waiting to transport milk to main processing industry. However, dairy farmers count losses because of different reasons.

An example is where the only milk processing industry in north-west, Mukamira dairy plant, stopped buying milk from farmers of five districts [7] because one foreign client has suspended the contract with the industry yet on another side, malnutrition is hitting children. However, does it mean that other local market is satisfied? Does it mean that (local) Rwandans consume enough milk?

Another case within the same region is where KAMU ZIRAKAMWA cooperative lost almost 500,000Frw in only four months because of inappropriate tanks and other facilities, in addition to other 6000 liters of damaged milk [8].

Figure 2: Farmers wait for selling milk in Kigabiro Milk Collection Center (MCC) [The NewTimes, 2016]

In the cities, the real-time information sharing among businesspersons favors the quickness of services and in turn, it contributes to the profitability of stakeholders. It essential to speed up the delivery not only to avoid the losses to businesses but also to avoid hunger, particularly to travelers and undernourished children.

Considering only Inyange dairy industry, the Figure 3 illustrates the concentration of 76 milk-trading activity in a part of Kigali city without showing other milk traders.

Figure 3: Milk selling zones are crowded in Kigali city [Inyange Ltd website]

To improve the business productivity, the rapid information sharing, between dairy and milk traders, will boost the effectiveness of different actors while favoring the good services to customers. The use of IoT technology will facilitate the dairy industries to know in real time the basic information from milk trading zones using long range communication protocols such as GSM/GPRS. More importantly, the industry will be able to know and avoid where they dilute milk by adding in water or other products, using quality sensors that check the milk constituents and send measurements to supplying company or other standards institutions.

This means that the transportation of milk from industry to milk traders will continue as usual but quickly avoiding the shortage of good milk to consumers. Therefore, the information sharing will facilitate and boost the good service delivery via the wireless infrastructures established in countrywide.

1.2. Background and Motivation

The milk commercialization involves the use of different communication technologies in both buying and selling. At different level of processing or consumption, the milk quality matters to avoid any harm of drinking or using fake milk. Nowadays, the basic treatment of milk at Milk Collection Centers requires the use of traditional local devices such as thermometer for temperatures, lactometer for quality, stainless-steel measuring scale for levels, etc.

As shown by Land O' Lakes International organization in **"**Rwanda dairy competitiveness program II report**"** [5], the milk production quantity and quality are key important to have the milk driven market and that is the main reason of establishing milk collection centers countrywide.

Since the introduction of information technologies in the functionality of many sectors, the outcomes are huge, such as real time monitoring and information sharing, improving the accuracy and good service delivery, minimizing the losses, favoring the services expandability, taking decisions based on facts…

Currently, there is no real-time technology linking all the milk business actors with the standards institution. Yet, both the quality and quantity monitoring and verification of produced and sold milk by competent professionals is important to avoid damages. Linking technologically both farmers' production at milk collection centers and milk trading zones' tanks to dairy Industries will improve the business flow.

In this growing farming sector, it is essential to use the technological means to know where there is excessive milk and where there is scarcity of milk using Internet of Things. The IoT can facilitate the tank talking to another tank or humans talking to tanks…..so that real time information helps decision makers to speed up the business flow hence avoid unnecessary damages while promoting the farming profession.

1.3. Problem Statement

The livestock as part of agriculture is done by more than 70% [9] of Rwandans. Farmers are investing more effort so that the commercialization of milk and its products bring wealth to them, and create business and employments to other people, at the same time provide healthier food to consumers, especially children under 5 years old. Both dairies and milk traders are waiting to benefit from their jobs of selling quantitatively the milk to consumers.

The losses occurring in milk business affect, in one way or another, many actors while the dilution of milk is dangerous to health of consumers, especially 38% [9] of children and adults are malnourished, and offence to standard requirements of food. Unfortunately, the food standards institutions are not able to tele-detect the quality of milk and other foodstuff.

Due to lack of remote real-time information sharing between the milk suppliers and milk traders, these last lose between 300,000 Frw to 1,400,000 Frw[1] per year because of poor communication. The use of telephone calls alone is not enough to overcome that loss.

The time between finishing the first supply and the next supply is long (1-2days), which determines the loss in business for both milk traders and processing industries, and partly on consumption point of view because they miss what they need as rich food especially for passing customers and above all the hungry children are affected more.

The mentioned and non-cited issues are weakening the farming profession, which is contributing around 24% [10] in country's GPD.

[1] Estimated calculations based on data collected from traders who sell between 100L to 400L per day

1.4. Study Objectives

1.4.1 General Objective

- Make an IoT system that monitors remotely the milk quantity and quality and facilitate the information sharing between legal milk supplier and traders, to ease the delivery decisions taking.

1.4.2 Specific Objectives

- Collect data sample from milk traders
- Analyze the collected data to identify the main problem.
- Design the IoT system that can detect the milk quantity and quality remotely in real-time.
- Prototype an IoT circuitry that can detect the milk quantity and quality and test it
- Write the dissertation and publish the paper.

1.5. Hypotheses

The delay of service delivery is causing an extra loss in business turnover that would help traders to expand their businesses and make more profit.

Based on the answers given by the milk retailers, applying internet of things technology in milk traders' tanks will contribute to the development of their businesses by reducing the time of receiving new delivery because they will notify the actual level of milk to their suppliers.

The milk tanks will be embedded with IoT devices that collected information about the level and quality using appropriate sensors. Using GSM module, these data will be transmitted to the suppliers who will use them to make important delivery decisions of supplying.

Because of diversified sources of milk, some being legal and others not, the milk quality maters to assure the health of consumers. It is easy for the standards institution to verify this aspect using internet of things remotely, to avoid dilution of milk.

1.6. Study Scope

In terms of resources, this research project will use the sensors (pH and ultrasonic), Arduino UNO microcontroller, GSM SIM900 module and IoT cloud platform (ThingSpeak). Only one sample device is implemented, simulated due to economic constraint

In terms of raw materials, the pH testing will be done in one-liter cup to verify it. Later, we will dilute milk with water to compare findings.

In terms of coverage, the project can work in Rwandan territory wherever the local network operators' GPRS coverage reaches.

1.7. Significance of the Study

Referring to national strategic transformation (NST) of the government of Rwanda and Sustainable Development Goals (SDG), the potential impacts are in three categories: economic, social and innovation.

Farmers as a big employment part of Rwandans will boost their economy significantly and contribute to the creation of new off-farming jobs associated to milk trading, as referred to Figure 4.

Both milk suppliers and retailers will benefit more by increasing their turnover while reducing the communication expenses. The speed of services delivery will increase, which will increase income.

The wellbeing of children and other malnourished consumers will be addressed because of ensured quality milk and localization of milk scarcity. Hence, the amelioration of children welfare.

Technically, the Internet of Things will be used in the improvement of existing industrial processes by improving the speed and quality of services. The dairy industry will revolutionize the way of communicating to its customers and have access to other useful business information.

The country in general will be developing that milk business and its share in GDP will always increase.

Figure 4: Milk business monitoring benefit both farmers, traders and consumers

The Figure 4 above shows the main sectors who will benefit from the well-controlled business of milk, avoiding the scarcity and dilution of milk on market in different zones of country.

1.8. Organization of the thesis

This thesis is organized in the following chapters:

Chapter 1 is the general introduction, which highlights the background of this project. The points described in it include the background and motivation, problem statement, objectives, hypothesis, scope and significance of this research.

Chapter 2 is the literature review, which describes the technical specifications of essential components used in the implementation of the prototype such as sensors, Arduino microcontroller, GSM SIM900 module and Thingspeak cloud platform. In addition, other research papers have been reviewed in part.

Chapter 3 is about different methodologies used in implementing the system prototype.

Chapter 4 is system design, which shows the main parts of project system such as IoT device, cloud storage and user interface by focusing on the how is used in the context of this project research.

Chapter 5 is about implementation and testing of the system where components assembling, programming, testing and designing the customization take effect. The flowchart is detailed to clarify the whole implementation process. Every part of the project is explained one by one based on the testing results obtained.

Chapter 6 is conclusion and recommendations, which ends the current research by showing the obtained results and highlighting some recommendations.

Appendix is the last part indicating the questionnaire used to prove the necessity of this research.

1.9. Thesis contribution

Technically, the implementation of this work proved the possibility of detecting milk data remotely, which is useful in contributing to development of milk business as profession and economic activity.

The measurement of milk data such as quality based on its acidity and quantity based on tank level have been achieved using appropriate sensors and accessed remotely, in real time, using GSM communication on IoT platform.

Chapter 2: LITERATURE REVIEW

The literature review is all about reviewing the essential components proposed in this project referring to other previous researchers. The remote milk monitoring necessitates the use of appropriate devices mainly the quality and quantity sensors and microcontrollers, while to communicate the detected values for remote analysis requires the use of communication technology like the GSM.

This chapter is divided into two parts, which are the review of the work done by other researchers and the description of the main components.

2.1. Main components description

2.1.1. Main Sensors: PH sensor and Ultrasonic sensor

The high attention to choose the prototyping sensors is necessary because of the milk nature to avoid impurity or other poisonous substance.

The first sensor proposed in this research project is the pH sensor. It is used to show the acidity or alkalinity of milk. The milk has a pH value in the range of 6 – 6.7, below that of pure water. It consists of the pH electrode plunged in liquid solution and the pH Module connected to microcontroller, as described in Figure 5.

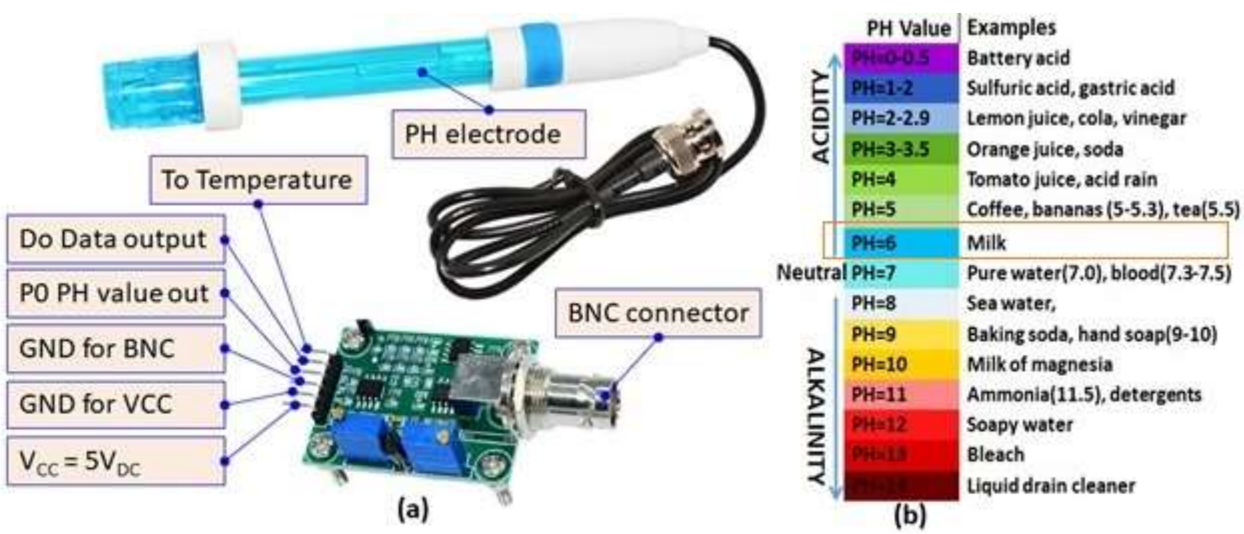


Figure 5: (a) PH sensor, (b) PH value range with examples solution [11] [12] [13]

Table 1: Specifications of PH sensor

Module power	5V
Measuring range	0 – 14 pH
Measuring temperature	0 – 60 ^{O}C
Accuracy	± 0.1pH (25^{O}C)
Response time	≈ 3 minutes
Working current	5 – 10mA
Power consumption	≤ 0.5watt
Pins description	Po, To, Do, Vcc, GND
Connector type	BNC

The second is the ultrasonic sensor, shown in Figure 6, used to measure the distance or level of consumed milk, hence the level of remaining milk in tank. It used the principle of sending sound wave that reflect back while meeting an obstacle.

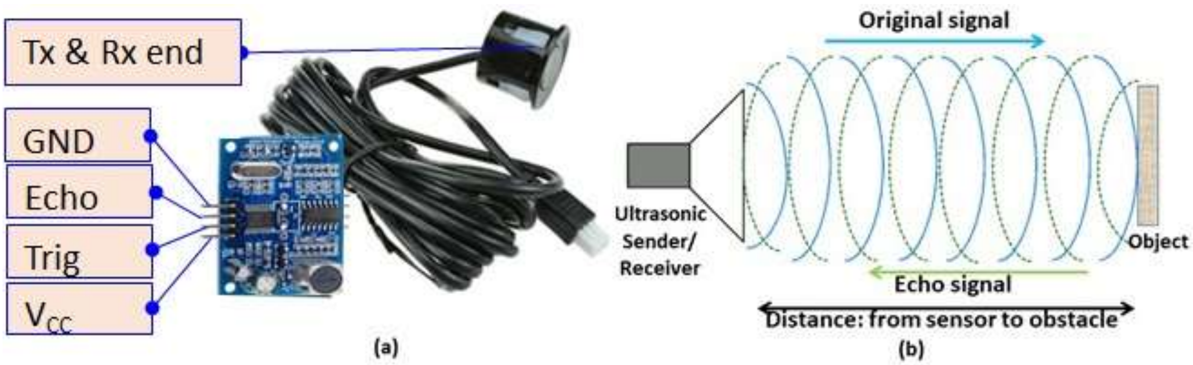


Figure 6: (a) Ultrasonic sensor (b) Working principle [14]

Table 2: Specifications of ultrasonic sensor

Working voltage	5V_{DC}
Working frequency	40kHz
Detection range	25 – 400cm
Measuring angle	< 50 degree
Working temperature	- 10 to 70 ^{O}C
Pins description	V_{CC}, Trig, Echo, GND
Waterproof	Yes
Using method	Transmit and receive (dual type)

2.1.2. Arduino Microcontroller

It is a programmable device comprising two parts: hardware with multiport and software (IDE). It accepts both analogue and digital inputs and outputs. It will compute all data from sensors directly coupled on its different input pins. [15]

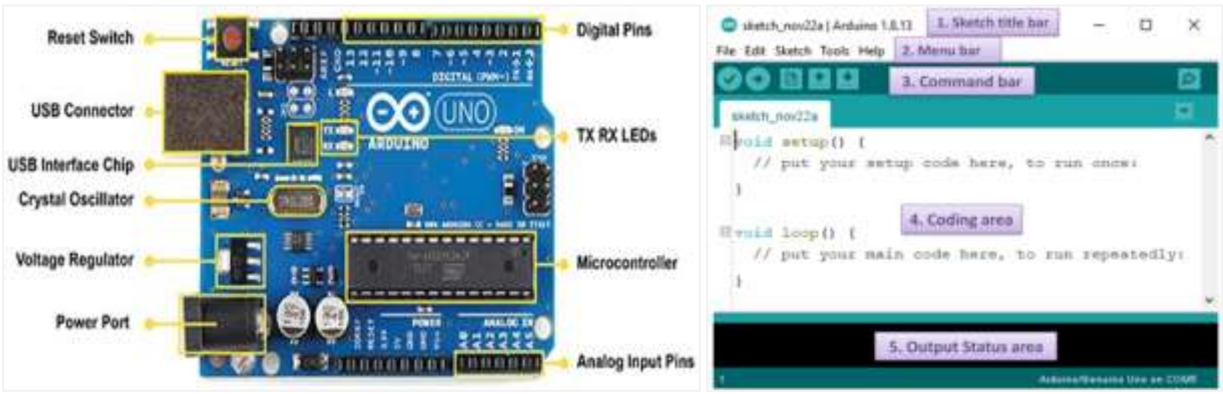


Figure 7: Arduino Uno and Arduino IDE [15]

Table 3: Arduino UNO Specifications

Microcontroller	ATMega328
Operating voltage	5V
Recommended supply voltage	7 – 12V
Digital input/output pins	14 with 6PWM output
Analogue pins	6
Power port type	USB and barrel jack
DC current per input/output pin	40mA
Clock speed	16MHz
SRAM	2KB
EEPROM	1KB

2.1.3. GSM communication module

The sensor data collected by different sensors and computed by the microcontroller will reach the destination using the GSM/GPRS communication protocol. The interesting parts here are the mobile station (MS) or GSM module embedded with SIM card, which is a hardware module, Figure 8, flexibly programmed depending on the target use. [16]

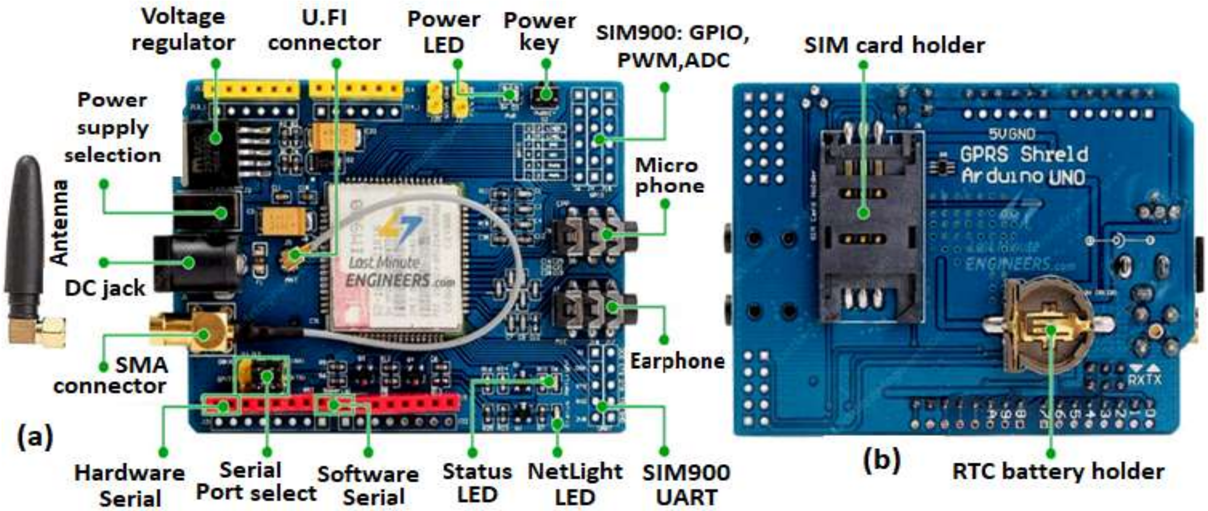


Figure 8: (a) Front, (b) Back sides of SIM900 GSM/GPRS shield [16]

Table 4: GSM/GPRS Specifications

GSM/GPRS Module	SIM900A
Operating Frequency band(MHz)	900, 1800, 1900
MODEM communication Interface	TTL UART
Baud rate	9600bps
Current requirement	<590Ma
Power supply	12V, 1A or 5V, 2A
Operating temperature	- 40 ^{O}C TO + 85^{O}C
Indicators	Power LED, status LED, Net LED
Compatible with Arduino Uno	Yes

2.1.4. ThingSpeak

The ThingSpeak is a open source platform used in IoT application. It provides a storage and API for the user using different protocols such as HTTP. Through it, various smart devices detect and communicate their status to remote places. Data analysis can be done using Matlab software integrated within it [17].

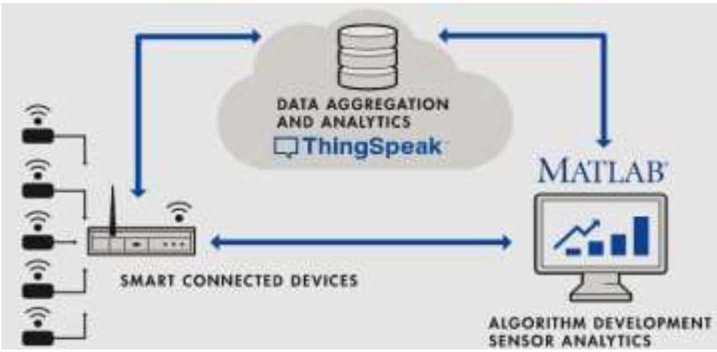


Figure 9: Illustration of ThinpSpeak IoT platform [17]

2.2. Review of other research paper

The first research paper reviewed is that of H. Haribabu et al [16], titled “an IoT Detection of Milk Parameters using Raspberry PI and GSM for Dairy Farmers”, is a paper aiming at measuring the quality of milk by checking different parameters and communicate them to either farmers or responsible institution.

One of sensors used is pH sensor used to measure the acidity level of milk as compared to other liquids, see Figure 5. Another device used is the lactometer to measure the purity of milk but it’s operated manually. It is very clear that mixing the milk with other liquids will change its pH value, either high or low, hence proving poor quality. The obtained values are stored in a web-server for future use. Those sensors connected to Raspberry Pi microcontroller to coordinate and process the detected changes that are locally displayed on LCD display. The values are sent to responsible institution for verification using GSM/GPRS communication technology to a server webpage.

In such system, the raspberry microcontroller used is very expensive. Moreover, the system is used on farmers’ side, which is not corresponding to this proposed idea, as summarized in Table 5. However, the use of ThingSpeak to, freely, analyze the data remotely is very useful, in addition to appropriate, but not enough, sensors.

The second one titled “Ultrasonic & GSM Module Based Water Level Monitoring System via IoT” is the system proposed by E.J. Smith et al [17]. They stress the importance of using the ultrasonic sensor to detect the water level in real time, and communicate it remotely using the GSM technology.

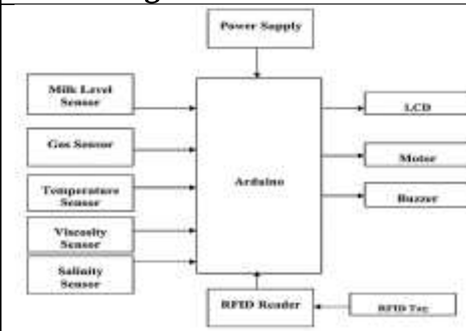
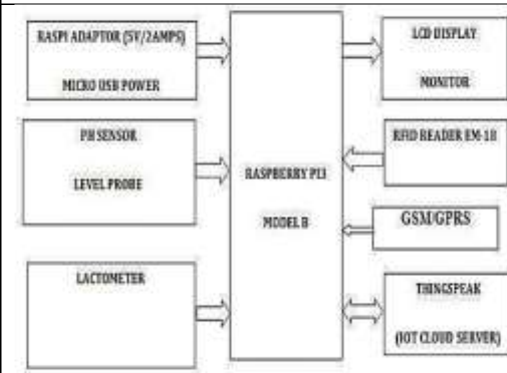
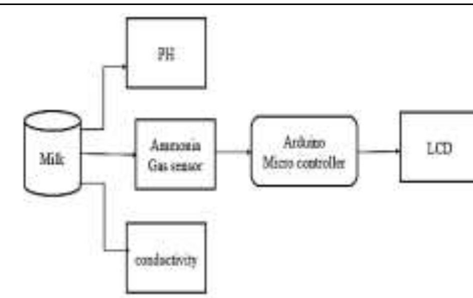
The ultrasonic sensor, shown in Figure 6, is used in my project because of milk level measurement in tank(s) where it uses is principle of sending a sound wave and receive the reflection after colliding with an obstacle, which is the top level of remaining milk. Its advantage is to provide accurate measures without touching on the milk; instead, it uses the principle of obstacle detection.

The third paper reviewed is called “IoT based Milk Monitoring System for Detection of Milk Adulteration”. It is the paper of Dr. G. Rajakumar et al [18], where they studied about the use of IoT in detection of milk quality in urban area as a factor to prevent the diseases caused by adulterated milk. According to them, when the milk is kept longtime, it develops smells due to bacteria that later may spoil it.

Various sensors such as temperature sensor (LM35), gas sensors (MQ6) are used to detect the level of milk crudeness, the salinity sensor to measure the quantity of salt as quality factor, the level sensor to measure the amount of milk, and the RFID reader (EM-18) to help customers' details and payment. All the sensors are connected to Arduino microcontroller [19], shown in Figure 7, which processes their readings and display them on LCD. This microcontroller has two important parts: the hardware and software. The hardware is a tangible board through which various sensors, actuators, communication protocols and other things are connected.

The system proposed is this paper is good in measuring the quality of milk in addition to low cost materials, but the fact that it cannot send recorded data, to responsible part, for further decisions, is the drawback to improve, as shown in Table 5. Therefore, it is not pure IoT system.

Table 5: summary comparison between reviewed papers with my research project

Authors	Papers	Paper short description	Drawback/Improvement	Block diagram
Dr. G. Rajakumar, Dr. T. Ananth Kumar, Dr.T.S.Arun Samuel, Dr. E.Muthu Kumaran. [18]	IoT based Milk Monitoring System for Detection of Milk adulteration	This paper studied about the use of IoT in detection of milk quality in urban area as a factor to prevent the diseases caused by adulterated milk. They use microcontroller to computer the milk quality parameters and an RFID tag for customers to auto serve oneself.	That paper is not full IoT system, only perception layer, because it misses some parts like network and application layers. In our proposal, a GSM module is added to send data to milk supplier(s) which uses the API to view remotely the information from the milk trading zone(s)	
K. Haribabu, Ch. Umashankar, S.V.S Prasad [16]	An IoT Detection of Milk Parameters using Raspberry Pi and GSM for Dairy Farmers	The paper is aiming at measuring the quality of milk by checking different parameters and communicate them to farmers or responsible institution	In that paper, they use lactometer for quality checking manually with farmers. Again, the Raspberry Pi used is very expensive. In our proposal, we proposed cheap microcontroller and sensors are automatic. Moreover, we extended the nutrients to be tested compared to that reviewed paper	
Valarmathy R.S, J.Haritha, Gowthaman S, Jawaharrajan B [22]	Detection of urea adulteration in milk using Gas sensor	Detection of milk adulteration based on smelling.	It is rather an embedded system instead of IoT system because there is not communication involved	

Chapter 3: METHODOLOGY OF SYSTEM PROTOTYPE IMPLEMENTATION

The research project here present comprises three sections, as summarized in diagram of **Error! eference source not found.**:

In data collection, a questionnaire Annex1 – milk traders is distributed to milk traders, considered as target group of this research project, in different areas. The purpose is to see the relevance of this research project compared with the objectives and its contribution to traders' daily activities. As the feedback from them is encouraging, then it is time to pass to the next step of implementation.

The prototyped solution comprises different electronic devices' categories such as sensors, microcontroller, GSM module, and the IoT platform. They are assembled together on printed circuit board and tested. Whenever the test results are not good, then calibrations and re-programming were conducted until expected results are obtained.

Having a successful prototype, then it is time to write the dissertation and publish a paper. The dissertation will be presented to academic panelist, after the approval of supervisors.

Having undergone the research work into three stages as mentioned in **Error! Reference source ot found.**, the Figure 10 below shows the implementation steps between assembling hardware and having a working system

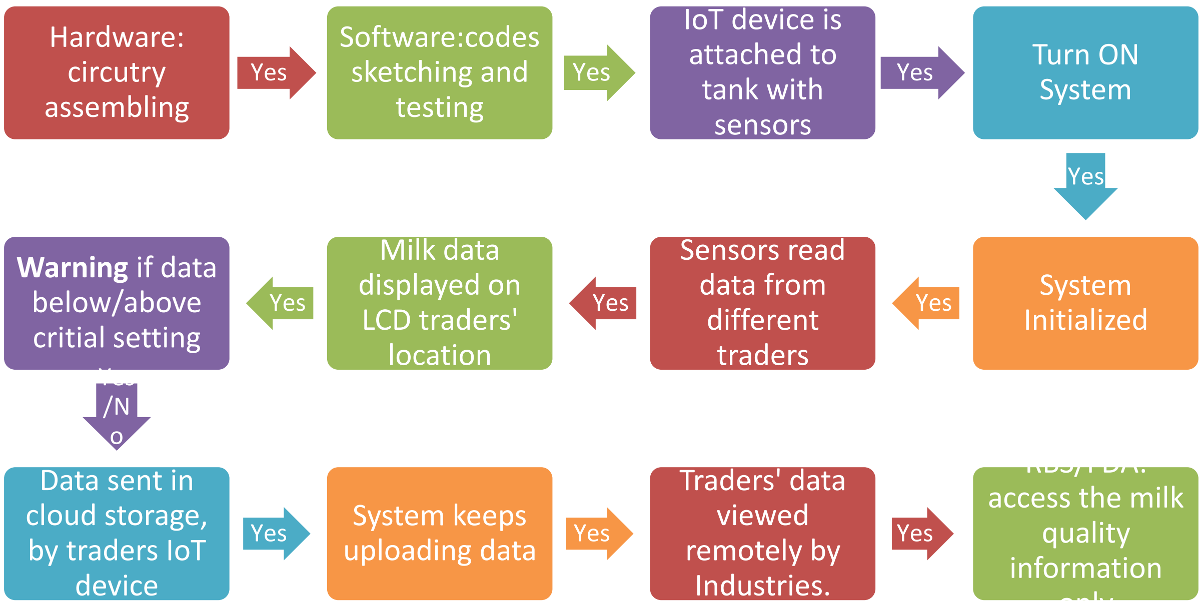


Figure 10: Summarized methodology of system functionality

Firstly, the milk tanks will be made smart by incorporating intelligent sensors – for reporting the milk's level and quality as acidity level – controlled by Arduino microcontroller. It is obvious that both the trading agent, supplier and customers will be able to see the quality of milk.

Secondly, the data from the microcontrollers, about the status of milk in tanks, will be sent in real time to the milk distributing industries, so that they act accordingly. This will avoid the lack of milk to the customers' side and, indirectly, speed up the milk delivery chain: from collection centres through processing industry to milk traders. Because of this chain, the farmers' production will be sold without a loss as the industry knows where there is a scarce or abundant milk i.e. trader's status. The GSM communication will be used for this purpose because it is cheap and its network coverage is available countrywide.

Chapter 4: SYSTEM DESIGN

As the general objective is to design and implement the IoT system able to detect, remotely, the level and quality of milk in the tank of traders, the main components involved are sensors, microcontroller and wireless GSM module as summarized in Figure 12. After the local sensing of data, as seen in Figure 11, they are transmitted to users periodically via the cloud storage through the base station (BS) scattered countrywide. The user interface will serve, not only, as an endpoint for decision maker, but also for statistical purpose.

Figure 11: Complete system diagram

4.1. Main parts of the system

The system is composed of three main parts named (i) IoT devices, (ii) the cloud storage and (iii) the user interface. The IoT device comprises sensors microcontroller and wireless communication module. There are as many instances of the IoT devices as there are traders. The Figure 12 illustrates the main part of the system:

Figure 12: Three main sections of system

The power of Hydrogen (pH) sensor, see Figure 5, is analog device used to measure the acidity level of liquids, and its scale is between 0 – 14. The good milk has pH value measuring around between 6.0 – 6.7. it's used by embedding it into the milk and waiting its response for around three minutes. Its pins and connection details can be seen in Figure 14. By consuming very small power (5Vdc), it can measure the pH value and temperature. It's stable, reliable,

The level sensor used in this research is the waterproof ultrasonic sensor, see Figure 6. It's used to detect the level on milk using its transmission (Tx) and reception (Rx) of sound wave capability. The level is equivalent to distance travelled by that sound wave. It provides an accurate, touchless distance between 25 – 400cm from its fixed position.

Both PH sensor and ultrasonic sensor provide stable data, consumes less power, are waterproof, weightless, withstand a wide range of temperature and fit in this application.

The Arduino Uno microcontroller is embedded in multiport board which facilitate the wiring with other components. It has many analog and digital pins that can host many input and output devices, yet it consumes less power. It can be powered from computer ($5V_{DC}$) or independent source ($12V_{DC}$). It has an IDE installed in computer and facilitate the programming tasks.

As the system is intended to link many milk traders' tanks to dairy industries and standards institutions across the country, the GSM/GPRS module will facilitate that transmission of data occurring from each tank independently. Different infrastructures are involved, from existing ones to the new incorporated IoT devices, to work closely so that data from anywhere reaches to the destination in a readable manner, i.e. read graphical and numeral representation.

Among many infrastructures involved in the design of Figure 11, they can be summarized in four layers, as follows:

4.1.1. Illustration of smart milk tank

Perception level: wherever there is milk in tank, its quantity and quality matters. The desired parameters are locally perceived using different sensors connected to microcontroller. The milk traders and farmers through their milk collection centres are found at this level.

The tank is made smart by integrating appropriate sensors to perform a certain specific such as level and quality, as illustrated in Figure 13

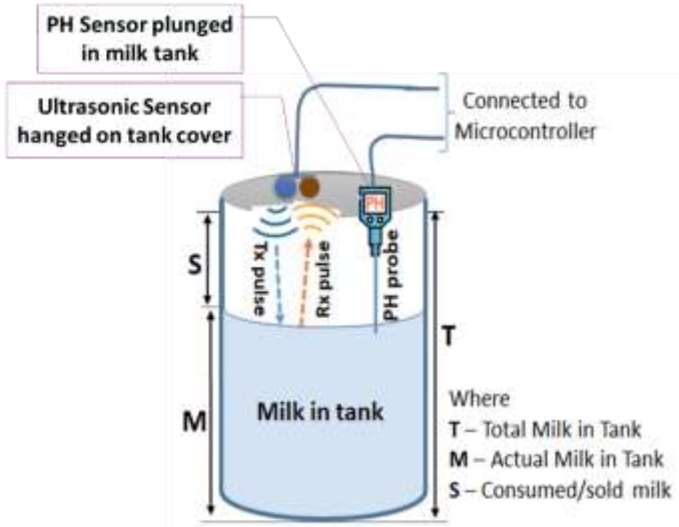


Figure 13: Illustration of Milk Tank with Sensors

Initially, the depth of the tank should be known. The milk remaining in tank is displayed on screen and browser by taking the difference between the total milk and sold milk. i.e. $\boldsymbol{M} = \boldsymbol{T} - \boldsymbol{S}$.

When the ultrasonic sensor is triggered, it generates sound waves emitted out via the transmit head. When the transmitted wave strikes an obstacle, it reflects and get received to the Receiver head. The microcontroller calculates the distance, varying between 0 – 400cm, travelled by that sound wave of ultrasonic sensor, using the following formula below.

$$\boldsymbol{Distance\ (cm)\ = (echo\ pulse\ width\ (\mu S)/58}$$

The pH probe sensor reads continuous or analogue value. The fact that Arduino pin reads between 0 – 5V corresponding to a pH varying between 0 – 14, the pH module is calibrated using offset POT so that a pH value = 7 be equivalent to Arduino reads of 2.5V from which other values can be adjusted. From there, the pH value of milk being between 6.0 – 6.7 is equivalent to an Arduino pin voltage between 2.14 - 2.39V and vice versa.

4.1.2. Elements integrated with microcontroller

The implementation of this projects required both local and remote access to basic information such as temperature, quality, quantity and data sent.

In that way, the LCD screen is used to show the transmitted data which the buzzer is used to alarm in case of critical events such as low milk, fake milk and inappropriate temperatures.

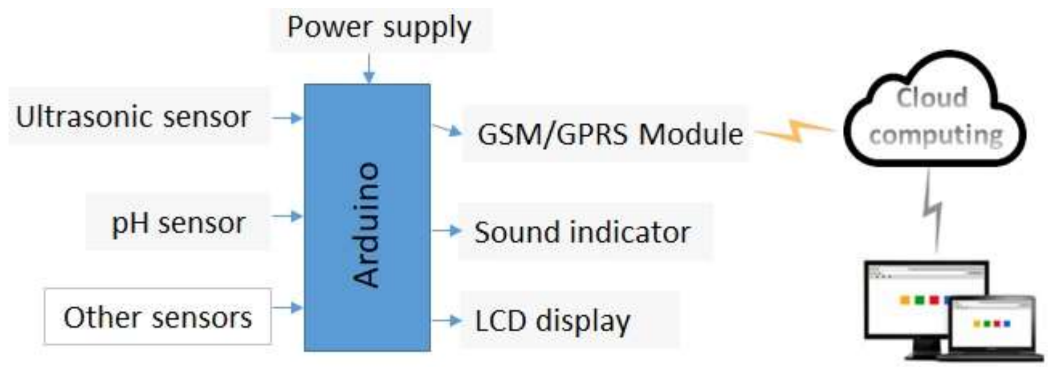


Figure 14: Circuit diagram showing all various elements connected to microcontroller.

For analytical purpose, only standard quality and level of milk data will be analysed.

Figure 15: Waterproof ultrasonic sensor (HC-SR04 M126) [14]

The ultrasonic sensor, see Figure 15, powered with 5Vdc, is used to detect an obstacle by the principle of transmitting the sound signal using its trigger terminal and detect its return back using its echo terminal after it hits an obstacle, like milk in this case.

To know the used and remaining milk om tank, Figure 13, the distance is calculated using the formula below.

$$\boldsymbol{Distance\ (S) = \frac{Time\ \times Speed\ of\ sound}{2}}$$

Where:

- Time is the necessary duration of reaching the obstacle and returning back to sensor receiver.
- Speed of sound take into account a signal frequency
- Distance is interval between sensor and milk level (obstacle)

By relating the distance between top and bottom with the depth of milk tank between 0 – 5 meters, it is possible to know exactly how much milk remaining in the tank.

pH Sensor

Figure 16: PH Sensor PH-4502C [11]

The PH means power of hydrogen and it is the measure of hydrogen ions contained in a solution. It is powered with 5Vdc and has different data pins but only Po pin is needed in this case.

The pH sensor, see Figure 16, indicates how much a solution is an alkaline or acid using pH value between 0 to 14 as shown in pH scale of Figure 5:

The PH electrode sensitivity will leads to analogue reading of acidity or alkalinity of any liquid solution in general and milk in this application

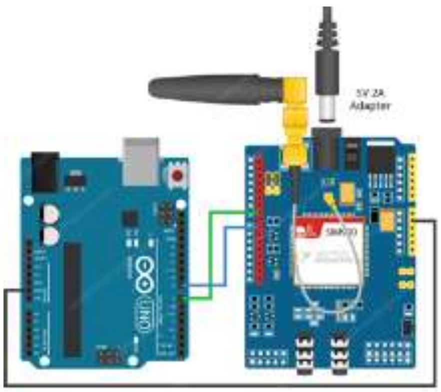


Figure 17: Figure 19: Interfacing Arduino with GSM/GPRS Module

Connecting SIM900 GSM/GPRS Shield to Arduino

To start with, connect D7(Tx) and D8(Rx) pin on shield to digital pin#7 and #8 on Arduino. Power the shield using external power supply rated 5V 2A or $12V_{DC}$ 1A.

GPRS Communication: wirelessly, this will create a transmission channel through which the milk data, from everyplace within GPRS' network coverage, will reach the central cloud server, via the base stations (BS). GSM is ideal in this application because of long distance communication and countrywide coverage. Data will be accessed through the browser using the http protocol.

Cloud storage level: data collected and transmitted periodically will be located at one place, accessible by authorized users. It is embedded with analytical tools to easy the milk data visualization and interpretation.

Chapter 5: SYSTEM IMPLEMENTATION AND TESTING

The implementation of the milk monitoring in Rwanda is achieved using various components as seen in Figure 18.

After analysing the needed solution, the program codes were written in Arduino IDE, show in Figure 7. Different components were assembled together, part by part, as seen in Figure 14, and the sketch was upload in the circuit of Figure 18. The calibrations were made to different components until the expected results were found on LCD display. The detailed process is shown in flowchart Figure 19 .

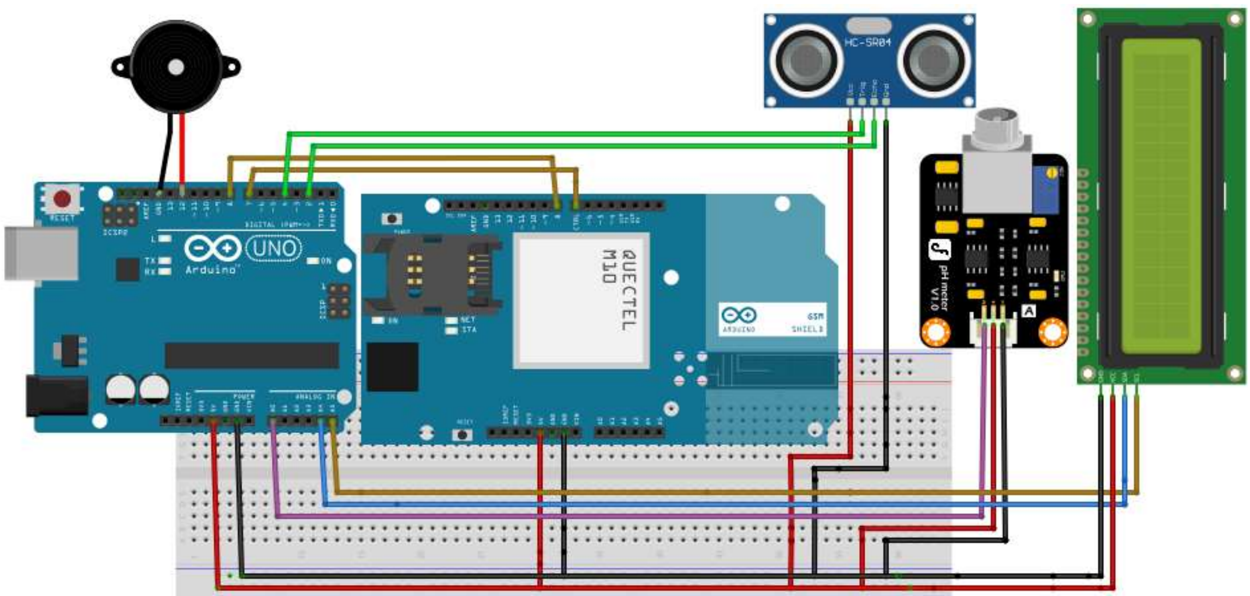


Figure 18: Implemented prototype circuit on board

Table 6: components used in prototype

Item description	**Number**
Arduino UNO	1
GSM/GPRS SIM900 Module	1
Ultrasonic sensor, HC-SR04 M126	1
PH sensor, PH-4502C	1
LCD display, 20x4	1
Sound buzzer	1
Prototyping board (PCB)	1
Jumper wires	17
PC laptop + Arduino IDE installed	1

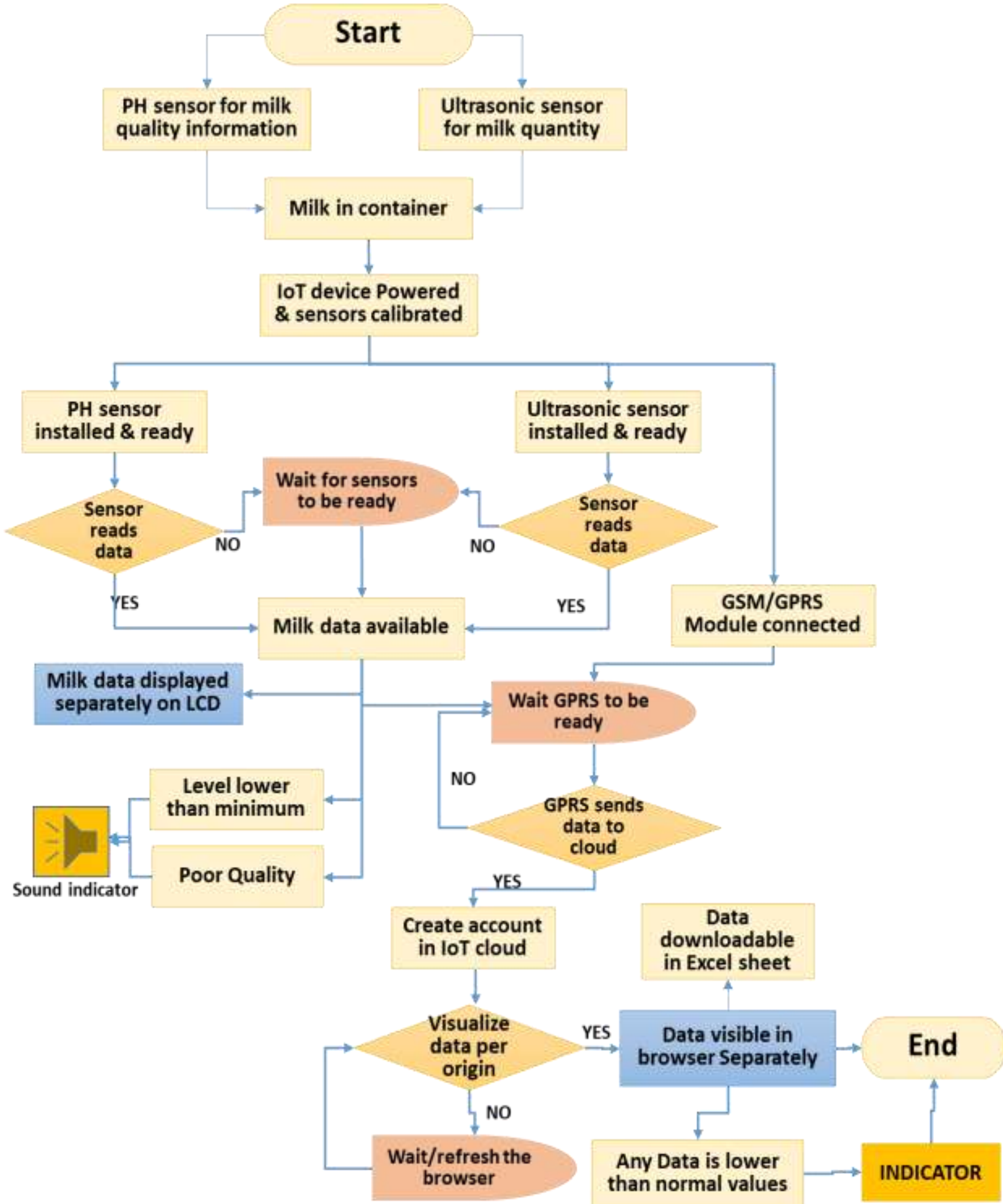


Figure 19: Implementation system Flowchart

As seen in figure above, having sensors and microcontroller plunged/hanged in the milk tank, then powered, the milk level and acidity are perceived and computed, and then displayed on LCD display.

For every change, higher or lower than the set range, there is a sound indicator through the buzzer. Having connected the GSM/GPRS Module with activated bundles to the Arduino microcontroller, the detected/computed status of milk will be transmitted to a remote cloud storage for remote analysis.

To have access on real time data transmitted to cloud, the user account is created and granted access to the channel through which data are available.

5.1. Arduino and Sensors codes analysis

The sketches are subdivided into four sections regarding the four tasks that the circuitry is going to perform, such are:

- Definition of all program sketch's elements
- Setup all input (sensors) and output (actuators) elements
- Running all sensors and actuators repetitively and provide output results locally
- Checking the GPRS Internet status
- Transmission of data to the cloud storage for remote accessibility

Section 1: declaration of each element of the circuitry

For the Arduino IDE and Arduino UNO to recognize inputs (sensors), and output (actuators), they have to be declared in the first part of the program. Together with other useful information like libraries, milk levels are defined here so that the Arduino recognizes them.

```
#include <SoftwareSerial.h>
SoftwareSerial gprsSerial(7,8);
#include <String.h>
#define echoPin 2
#define trigPin 4
#define LEDPin 13
//#define buzzer 8
int MaxLevel = 100;
int MinLevel = 30;
int duration, TankMilk;
const int analogInPin = A0;
int sensorValue = 0;
unsigned long int avgValue;
int buf;
float phValue;
```

Section 2: running the code once if the device works

In this part of the sketch, the pins of Arduino UNO, whether analogue or digital, are assigned roles such as input and output referring to element connected on them. Also, Serial Monitor is defined here for monitoring the local sketch running status in Arduino IDE as well as GPRS connectivity status.

```
void setup () {
  gprsSerial.begin(9600);
  Serial.begin(9600);
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(LEDPin, OUTPUT);
  pinMode(buzzer, OUTPUT);
 pinMode(A0, INPUT);
}
```

Section 3: running the code repetitively if the device works

Using mathematic formulas, the milk level and pH value are calculated. Moreover, the delay time was set between two consecutive sensors' readings. Each sensor works independently of another.

```
void loop()  {
/Calculating the level or quantity of consumed milk
        digitalWrite(trigPin, LOW);
        delayMicroseconds(2);
        digitalWrite(trigPin, HIGH);
        delayMicroseconds(10);
        digitalWrite(trigPin, LOW);
        duration = pulseIn(echoPin, HIGH);
        TankMilk = duration/58;

// Determining the acidity of milk in tank using PH
       buf=analogRead(analogInPin);
       avgValue=0;
       avgValue+=buf;
       float pHVol=(float)avgValue*5.0/1024/6;
       float phValue = -5.70 * pHVol + 8.7;
      delay(5000);   //Delay before next reading.
```

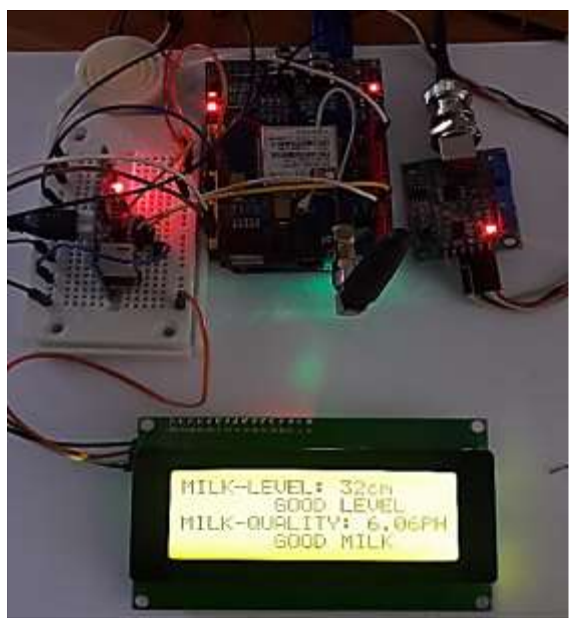


Figure 20: Milk data reading on LCD display

5.2. Arduino and GSM/GPRS codes analysis

After the Arduino Uno computed the detected data from sensors and displayed them on LCD, then it's time to send them on cloud. Having GSM/GPRS module interconnected with microcontroller, it will carry every load of given data to its destination if some conditions are fulfilled, such as GPRS status (AT), SIM card APN name, APN password and SIM PIN. Other conditions to verify includes but not limited to verification wireless connection (AT+CIICR), local IP address (AT+CIFSR), etc. The sample Arduino IDE serial monitor verification is shown in **Error! Reference source not found.**.

Section 4: Verification of GPRS internet connection

```
void GPRS_Initialization()     {
if (gprsSerial.available())
Serial.write(gprsSerial.read());
gprsSerial.println("AT"); //check the status
gprsSerial.println("AT+CPIN?"); //verify pin
gprsSerial.println("AT+CREG?");
gprsSerial.println("AT+CGATT?");
gprsSerial.println("AT+CIPSHUT");
gprsSerial.println("AT+CIPSTATUS");
//connection status
gprsSerial.println("AT+CIPMUX=0");
gprsSerial.println("AT+CSTT=\"internet\"");
//start task and setting the APN,
gprsSerial.println("AT+CIICR"); //bring
wireless connection
gprsSerial.println("AT+CIFSR"); //get local
IP address
gprsSerial.println("AT+CIPSPRT=0");
}
```

Figure 21: GPRS setting verification on Serial monitor shows the time and each status

Section 5: Transmitting the detected data to cloud storage (ThingSpeak)

First of all, before this step is achieved, the account, API link and API Key are obtained from the cloud platform's channel.

After verification of different parameters of GPRS and SIM card, the it is time to send data online.

Secondly, the GPRS module will initialise the sending to cloud process by verifying the TCP and API ports. Precisely, the GPRS will send data in API fields as created in ThungSpeak platform. In this case, the milk level is sent in filed1 and pH value is sent in filed2.

Depending on internet condition, data will be sent periodically. As defined in sketch, the period was 5second.

```
GPRS_Initialization();
gprsSerial.println("AT+CIPSTART=\"TCP\",\"api.ThingSpeak .com\",\"80\"");
//start up the connection to cloud
GPRS_StartSending();
String str="GET https://api.ThingSpeak
.com/update?api_key=LTRZDEY54VLEJOYF&field1=" + String(TankMilk)+"
" "&field2=" + String(phValue);
gprsSerial.println(str);        //begin send data to remote server
GPRS_Sending();
}
void ShowSerialData() {
while(gprsSerial.available()!=0)
Serial.write(gprsSerial.read());
}
void GPRS_StartSending()    {
gprsSerial.println("AT+CIPSEND"); //begin send data to remote server
}
void GPRS_Sending()  {
gprsSerial.println((char)26); //sending
delay(5000); //waiting for reply, important! this time is based on the speed of
Internet
gprsSerial.println();
gprsSerial.println("AT+CIPSHUT"); //close the connection
}
```

When the milk is being consumed, the distance or gap between remaining milk and top of tank increases as indicated in graphics of Figure **22**. Whether the milk is full or not, it doesn't affect the PH value as it varies based on concentration of hydrogen in milk only, see Figure **23**.

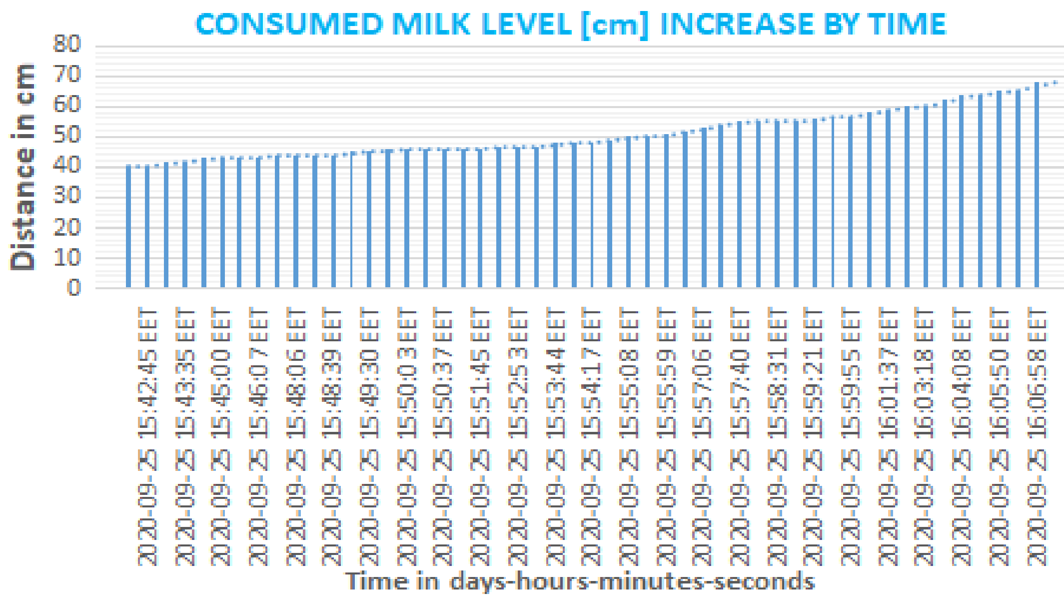


Figure 22: Consumed Milk level increases by time

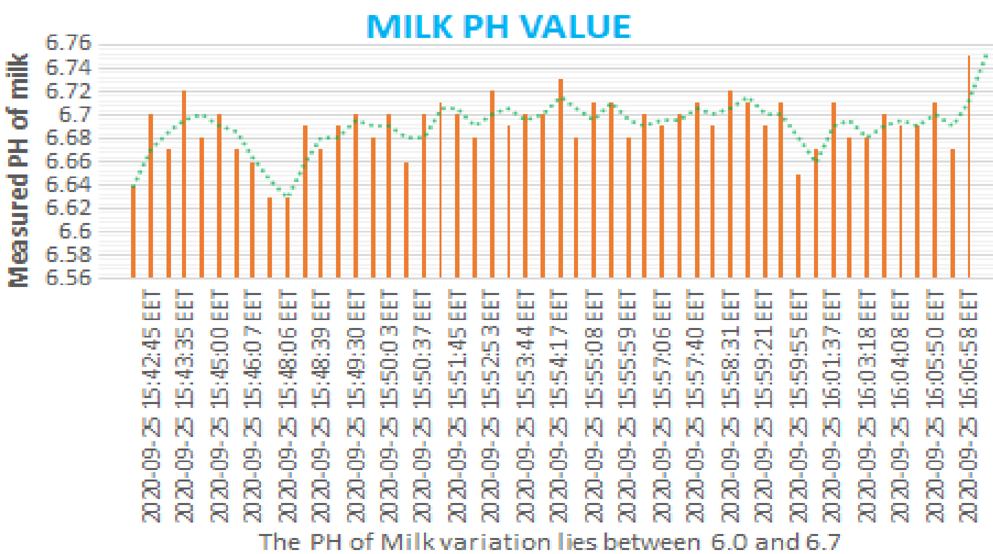


Figure 23: The milk acidity varies from 6.0 to 6.7 in the range of 0 to 14

The level (measured in cm) is proportional to the distance between the level of milk and the top of tank. The longer is the distance, the fewer is the milk in tank, see **Figure 25.** The PH value of milk, as analogue value, is varying between 6.0 and 6.7. The PH higher than 6.7 or less than 6 means that the milk is damaged, i.e. either diluted, adulterated or something

5.3. User Interface and Data visualization

In this step different configuration in ThingSpeak are made to create an account which will help to get two important information: cloud channel and API Key.

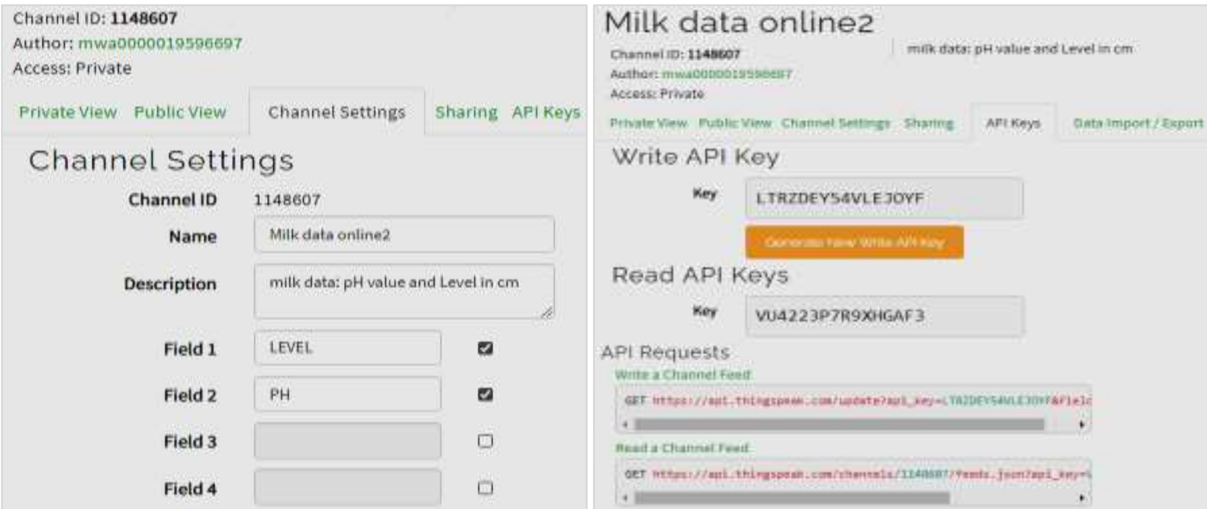


Figure 24: screenshot of channel and API

Data transmitted through GPRS module are stored in cloud. From there, the allowed user can access them through an interface as shown in **Figure 25**.

Figure 25: Screenshot of consumed Milk Level and PH in Thingspeak (user interface)

User interface or business level: data stored in the cloud storage can be accessed via the browser on any computer, tablet or mobile device connected on Internet. To access it, there need to login using username and password. Moreover, a certain ThingSpeak Channel is accessed by someone authorised.

In addition to different menus, it will display different views of data stored in cloud, either in graphics, numerical or visual display

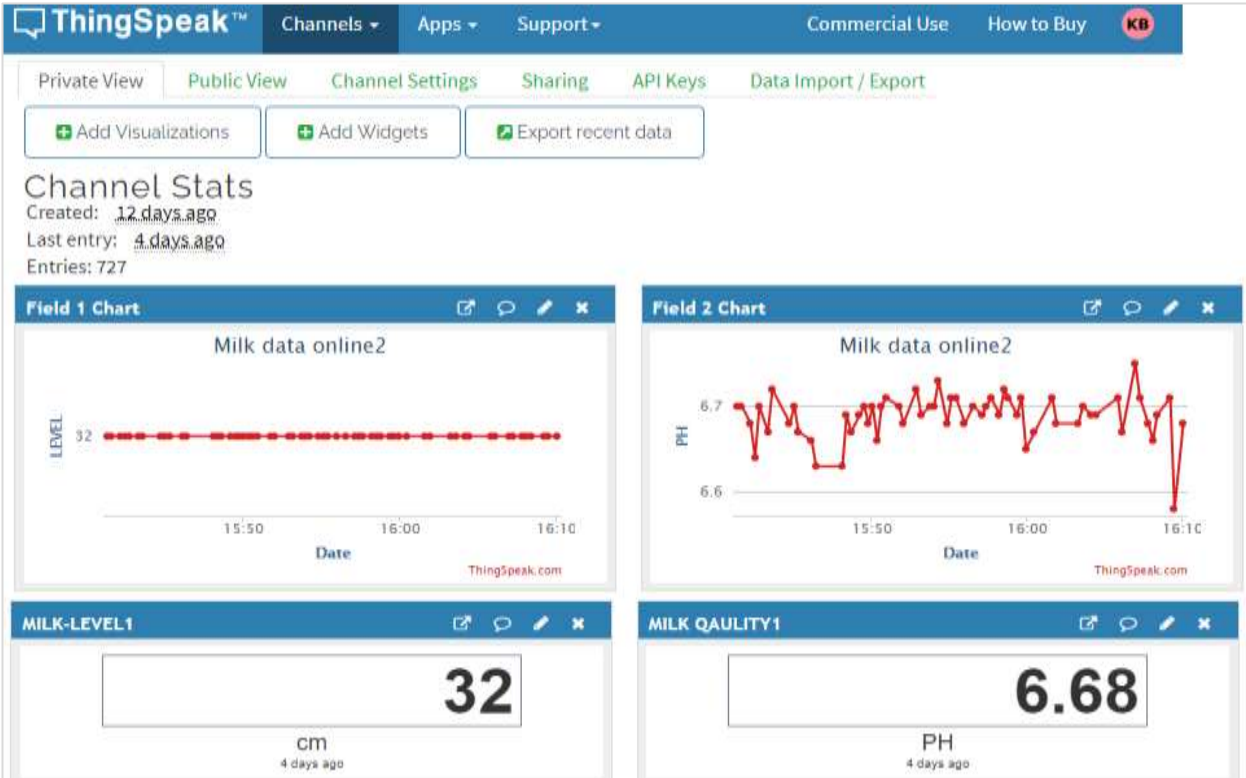


Figure 26: screenshot showing different parts of user interface

A sample of data collected on Sept 25th, 2020 from 3:48PM to 4:10PM is shown in excel sheet (Table 7) below:

Table 7: Sample Milk data stored in cloud at 25/09/2020

entry_id	Data created_at	Consumed milk [Level in cm]	Milk PH Value
670	2020-09-25 15:42:11	40	6.68
671	2020-09-25 15:42:28	40	6.64
672	2020-09-25 15:42:45	40	6.7
673	2020-09-25 15:43:18	42	6.67
674	2020-09-25 15:43:35	42	6.72
675	2020-09-25 15:44:43	43	6.68
676	2020-09-25 15:45:00	43	6.7
677	2020-09-25 15:45:16	43	6.67
678	2020-09-25 15:46:07	43	6.66
679	2020-09-25 15:46:24	44	6.63
680	2020-09-25 15:48:06	44	6.63
681	2020-09-25 15:48:22	44	6.69
682	2020-09-25 15:48:39	44	6.67
683	2020-09-25 15:49:13	45	6.69
684	2020-09-25 15:49:30	45	6.7
685	2020-09-25 15:49:47	46	6.68

686	2020-09-25 15:50:03	46	6.7
687	2020-09-25 15:50:21	46	6.66
688	2020-09-25 15:50:37	46	6.7
689	2020-09-25 15:50:54	46	6.71
690	2020-09-25 15:51:45	46	6.7
691	2020-09-25 15:52:02	47	6.68
692	2020-09-25 15:52:53	47	6.72
693	2020-09-25 15:53:10	47	6.69
694	2020-09-25 15:53:44	48	6.7
695	2020-09-25 15:54:00	48	6.7
696	2020-09-25 15:54:17	48	6.73
697	2020-09-25 15:54:51	49	6.68
698	2020-09-25 15:55:08	50	6.71
699	2020-09-25 15:55:25	50	6.71
700	2020-09-25 15:55:59	51	6.68
701	2020-09-25 15:56:32	52	6.7
702	2020-09-25 15:57:06	53	6.69
703	2020-09-25 15:57:23	54	6.7
704	2020-09-25 15:57:40	55	6.71
705	2020-09-25 15:58:14	55	6.69
706	2020-09-25 15:58:31	55	6.72
707	2020-09-25 15:58:47	55	6.71
708	2020-09-25 15:59:21	56	6.69
709	2020-09-25 15:59:38	57	6.71
710	2020-09-25 15:59:55	57	6.65
711	2020-09-25 16:00:29	58	6.67
712	2020-09-25 16:01:37	59	6.71
713	2020-09-25 16:01:54	60	6.68
714	2020-09-25 16:03:18	60	6.68
715	2020-09-25 16:03:35	62	6.7
716	2020-09-25 16:04:08	64	6.69
717	2020-09-25 16:04:25	64	6.69
718	2020-09-25 16:05:50	65	6.71
719	2020-09-25 16:06:07	65	6.67
720	2020-09-25 16:06:58	68	6.75

Note from the table above:

- Entry_id is the numeration of recorded data
- Field 1 is the level/quantity of milk in the container
- Field 2 is the pH measure of milk
- Latitude and longitude is about the location of the milk trader
- Elevation is about the altitude

Chapter 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusions

At the beginning of this research a questionnaire was set to understand the relevance of using IoT in sharing information in the milk business. The feedback from milk traders, in Table 8, was very supportive to our project objectives because they lose too much money, at different levels due to delayed services.

In fact, the target was to determine the quantity and quality of milk remotely and transmit these data wirelessly to milk suppliers, using GSM/GPRS communication, so that someone responsible can access them through a browser and take business decisions that may improve the milk business flow chain while reducing the financial loss of traders, instead increase their benefits. Generally, the objectives as set at the beginning have been achieved as follows:

First of all, data collection was done from ten different milk traders. Due to losses traders face, the proposed solution can help to reduce or eliminate the financial losses, read Table 8

Then, the next objective was to designing and prototyping an IoT system able to monitor remotely the level of milk in tank as well as its PH as one parameter of milk quality. It has been achieved successfully. As indicated in Table 7 and Figure 26, remote data observation was achieved to different milk levels and milk PH concentration. As proved in chapter 5; local and remote data visualization was successfully done using LCD and Thingspeak respectively.

Finally, the objectives of writing a dissertation and publishing the paper were also achieved, where our research paper was submitted and presented in SOFA 2020 (9^{TH} International Workshop on Soft Computing Applications 27-29 NOV-2020 ARAD, ROMANIA)

6.2. Recommendations

Despite the achievement of expected results, we recommend the following:

- The project would be implemented at large scale with implementation of many IoT devices, in different locations and real tanks filled with milk. This was not done because of financial limitations, and the university could not facilitate at all.
- This project can be turned into a business opportunity with the support of the university and other stakeholders who are funding the researches, any support of this kind is highly promoting the innovative ideas.

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APPENDICES

Annex1 – milk traders Questionnaire

For the research project to affect successfully the intended group, the target customers should get involved by answering questions that favor the realization of it. In that regard, the asked questions, here down, were translated in Kinyarwanda to facilitate the correct understanding and accuracy of answers.

Table 8: Questionnaire and Feedback from Milk Traders

Questionnaire	Trader 1	Trader 2	Trader 3	Trader 4	Trader 5	Trader 6	Trader 7	Trader 8	Trader 9	Trader 10
1. Are you a milk trader? ☐ Yes ☐ No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Who is your milk supplier? ☐ Dairy industry ☐ Farmers ☐ Others	Dairy	Others	Others	Others	Dairy	Others	Others	Others	Dairy	Dairy
3. How much milk do buy at once? ☐ Less than 300L ☐ Between 300 and 800L ☐ Above 800L	300–800L	<300L	<300L	<300L	>800L	<300L	<300L	<300L	300–800L	>800L
4. Approximately, how much milk do you sell per day? ☐ Less than 50L ☐ Between 50 and 150L ☐ Between 150 and 500L ☐ Above 500L	150–500	150–500	<50	50–150	150– 500	150– 500	<50	50–150	150–500	150–500
5. In how many days do you sell your supplied milk batch? ☐ Between 1 and 3 days ☐ Between 3 and 7 days ☐ Above 7days	1–3 days	1–3 days	1–3 days	1–3days	1–3days	1–3 days	1–3 days	1–3days	1–3days	1–3 days

6. How long-time do you wait for the next milk supply? ☐ By 1hour ☐ Between 1 and 5 hours ☐ Between 5 and 24hours ☐ Above 1days	1hour	1–5hrs	>1day	1–5hrs	1–5hrs	1–5hrs	>1day	1–5hrs	1–5hrs	1hour
7. Which method do you use to request for milk-supply? ☐ Telephone call(s) ☐ Telephone SMS ☐ Internet (email, chat...) ☐ Others	Internet	Others	Calls/sms	Calls	Internet	Others	Calls/chat	Calls	Calls	Calls/chat
8. Approximately, how much do you spend to request for new milk-supply? ☐ Around 100F ☐ Between 100 and 500 ☐ Above 500	100-500	100-500	100-500	100-500	100-500	100-500	100-500	100-500	100-500	100-500
9. How do you know the milk remaining in your tank? ☐ Approximation ☐Open and have a look ☐Use scaled bar (wood or metal) ☐Use an embedded device	Embed device	Scaled stainless steel	Approx	Open/ look	Embed. device	Scaled stainless steel	Approx.	Open/ look	Open/ look	Embed. device
10. Do you believe, a technological way to notify the level of milk to your supplier would help you? ☐ Yes ☐ No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes