CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	Low-power wireless liquid monitoring system using ultrasonic sensors
Authors	Viswanath, Samarth;Belcastro, Marco;Barton, John;O'Flynn, Brendan;Holmes, Nicholas;Dixon, Paul
Publication date	2015-03-01
Original Citation	Viswanath, S., Belcastro, M., Barton, J., O'Flynn, B., Holmes, N. and Dixon, P. (2015) 'Low-power wireless liquid monitoring system using ultrasonic sensors', International Journal on Smart Sensing and Intelligent Systems, 8(1), pp. 26-44. doi: 10.21307/ijssis-2017-747
Type of publication	Article (peer-reviewed)
Link to publisher's version	10.21307/ijssis-2017-747
Rights	© 2015, the Authors. This work is licensed under the Creative Commons CC BY-NC-ND 4.0 license. - https://creativecommons.org/licenses/by-nc-nd/4.0/
Download date	2026-11-07 09:38:50
Item downloaded from	https://hdl.handle.net/10468/13262



UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh



LOW-POWER WIRELESS LIQUID MONITORING SYSTEM USING ULTRASONIC SENSORS

Samarth Viswanath[1], Marco Belcastro[1], John Barton[1], Brendan O'Flynn[1], Nicholas Holmes[2], Paul Dixon[2]

[1]Tyndall National Institute, UCC, Dyke Parade, Cork, Ireland

[2]Brockley Group, 1 Abbey Street, Howth, Co Dublin, Ireland

Email: samarth.viswanath@tyndall.ie

Submitted: Nov. 12, 2014 ***Accepted: Jan. 5, 2015*** ***Published: Mar. 1, 2015***

Abstract— Monitoring Systems are necessary to understand the changes that take place in environments. Remote monitoring and data collection systems are useful and effective tools to collect information from bulk storage tanks and to monitor the same. The measurement of liquid inside the tank is most important and such systems are useful in industries which are categorized as safety critical systems. This paper presents the architecture and initial testing results of a low power wireless system for tank level monitoring using ultrasonic sensors.

***Index Terms*—GSM, remote monitoring, ultrasonic sensors, tanks, low-power.**

I. INTRODUCTION

Storage tanks are artificial containers that hold liquids, compressed gases (gas tank) or mediums used for the short- or long-term storage of heat or cold. Large above ground storage tanks filled with hydrocarbon and hazardous liquids such as oil, oil derived products, chemicals and process plant liquids are in widespread use in the UK, Europe and throughout the world. The tanks are generally spread across a large area and use manual detection and measurement methods which are still under development. This makes it more laborious and time consuming to monitor the tank levels [1]. Remote monitoring and data collection systems are necessary to collect information from the tanks and monitor the same. So it is necessary to build a system which can be accurate, fast in measurement and simple to install and handle, but has an intelligence [2] which takes decisions in real-time and alerts and communicates when necessary. The data acquisition is done by the sensors used to sense the changes in the liquid level of the tank and is stored in the system's memory. A server collects the information sent from the onboard micro-controller through a GSM modem in the tank; saves it to a database and displays it on a website graphically. Such intelligent monitoring systems help in effective management of tanks, by assessing the status of the tanks periodically allowing optimized logistical supply of product and minimized inventory holding [3]. Efficient utilization of the low power modes of the microcontroller reduces power consumption and extends the longevity and reliability of the system with less maintenance cost [4]. Innovative solutions to tackle emergency applications need to be designed for critically sensitive application and can be achieved by developing effective embedded software, WSN architectures and communication protocols, which are robust, thereby increasing the lifetime of the network [5]. Analog to Digital Converters (ADC's) can be used to interface the sensors, which are used in data acquisition and sensing the parameters, to help in building sensor interface to the control unit (microcontroller) [6]. The data which is collected needs to be distributed and can be done by WSN nodes which consume low power and can have the intelligence for self-organization [7]. Scalability is another important parameter and determines the longevity of the system. A system thus developed should be scalable without major changes to the working system [8]. There are systems which have been implemented for specific liquids like water. Typically, the measurements of liquids are done using various sensors which need physical contact with the liquid. These might induce wear and tear and introduce maintenance costs and decrease the longevity of the system [9]. Ultrasonic sensors can be used to

sense the liquid level by placing the sensors at a specified portion in the tank, calculating the level of liquid by time of flight of the ultrasonic wave and correlation with respect to the dimension of the tank, to get a more accurate value [10]. The values thus collected needs to be sent to a server using a wireless communication medium, so that this can be correlated at the server for display on the tank software system [11]. The data collected at the server end is displayed on a GUI , thus communicating to the user about the level of liquid, in real time and also evaluating the variation of liquid levels over a period of time [12].This would accommodate efficient storage, dispensing of liquids and chemicals inside the tanks. As GSM technology is used, it helps the system to be installed in industries, liquid storage fields, oil-tank and trucks. These measurements are sent to a server via a GSM module [13] through GPRS. The GPRS is activated and the TCP/IP sockets are used to communicate to and from the server. The server stores the values in memory and ensures that fluid inventory levels are maintained, and helps in identifying problems such as tank leaks and fluid theft [14].

The various components of the system includes an ultrasonic sensor, a thermistor to get the temperature values of the system, a microcontroller which contains the processor and the analogue to digital converter to measure the temperature[15] and the GSM module used to connect to the server. The processing of the sensor data is done by the microcontroller and communicates to the server periodically as defined during installation. Addition of the nodes or system to the main network is simpler.

Figure 1 shows the working diagram of the tank monitoring system. The Base Station contains the server which is a display unit displaying the changes on the webpage. The telemetry unit containing the microcontroller, GSM module for radio communication and the sensors are placed inside the tank as depicted in figure 1.

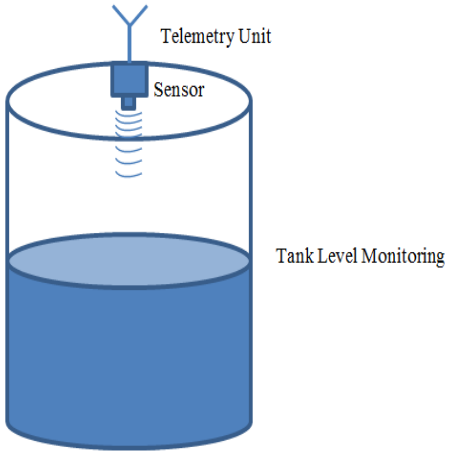


Figure 1. Tank Monitoring Unit

II. THE MEASUREMENT PRINCIPLE

An ultrasonic sensor is used to sense the amount of liquid inside the tank. These sensors send out high frequency waves which are reflected back when it strikes an object or liquid surface [16]. The time span between the transmitting and reflecting waves is measured by the microcontroller. This time of flight is used to determine the distance travelled by the waves, and extrapolate the depth of the liquid in the tank from the point where sensor is placed [17].

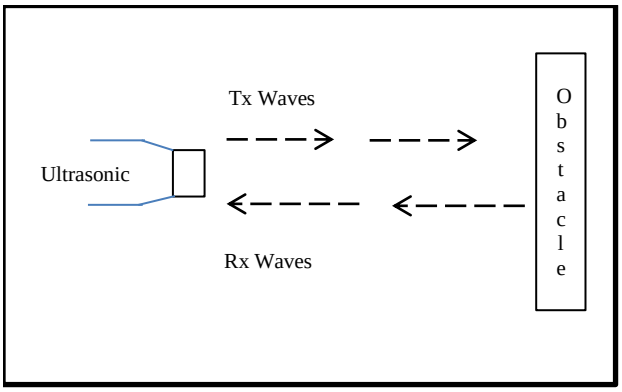


Figure 2. Operation of Ultrasonic sensor

The microcontroller sends a pulse through the software code, to the ultrasonic sensors which in turn transmits a wave form. Simultaneously, a timer in the software code is activated and runs until the waveform is received back. Once the waveform is received, the sensor sends a signal to

the microcontroller and the timer value is counted and the distance is determined. The microcontroller has various timers and timer 3(TIM3) is used because it consumes relatively less current (0.46mA) when compared to all the other timers present in the microcontroller. The software code used here takes three different ranges into consideration to find the distances. The ranges are 1) Short Range, 2) Medium Range and 3) Long Range.

The depth of the liquid is calculated accordingly and stored in the flash memory available for transmission to the server via the GSM Module.

III. SYSTEM STRUCTURE

The various modules used in the system can be divided into four subsystems which are as follows:-

1. Ultrasonic sensor: - The ultrasonic sensor is placed with its face directed to the liquid surface. The module is connected to the microcontroller which is used to determine the depth of the liquid in the tank by measuring the time of flight [18].

2. Microcontroller: - An ARM based 32 bit controller, the STM32F100R8T6B is used to control the overall operation of the system. This controller has an analogue to digital converter, two USART links and also has features which enable the system to go to low-power mode.

3. GSM Module: - The GSM module used here is a Huawei MG323-B which uses the serial communication link to and from the microcontroller. This is a UART link and uses AT Commands to communicate with the GSM module and configures the same to GPRS mode and sends and receives packet of data wirelessly [19].

4. Server: - The GSM module directly connects to the server which collects these values and represents them on the webpage graphically. The data is tabulated and the variation of liquid is shown on a graph. These readings make the system more user-friendly and also communicate the information to the user more effectively.

a. Components of the System

The components of the system can be divided into software and hardware:-

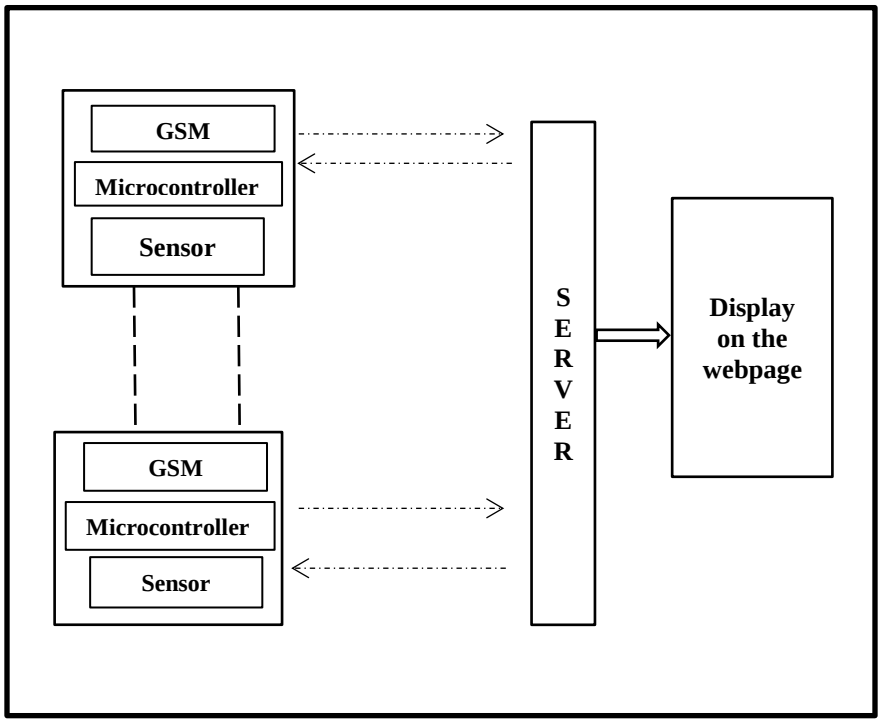


Figure 3. System Block Diagram.

a.i. Hardware

The hardware of the system consists of the following:-

1) Printed Circuit Board (PCB)

The printed circuit board is designed to facilitate the placement of the microcontroller and other components and the various interfaces that would be placed on the board so that the system runs as per the requirement.

The PCB has various functional blocks which include:-

i. *Power*: - The power block contains a voltage regulator which provides various voltage levels to system components like the ultrasonic sensor, GSM, e.g. 3V is required by the microcontroller. A low drop LDO regulator is used to provide voltage to the ultrasonic sensor. Electrical isolation and reduction of noise which might be generated is addressed during the design and placement of components on the PCB.

ii. *Microcontroller*: - This block consists of the microcontroller, an external crystal and the reset switch. This is the topmost layer and has direct attachment to the external world via reset switches. The microcontroller has these features as listed below:-

1. Arm Cortex M3 32 bit processor with18 KB of flash.
2. RTC (Real-Time clock) with 32 KHz external oscillator.
3. Low-power modes- sleep, stand-by and stop modes.
4. 16 channel 12-bit ADC for higher accuracy of measurement of the analogue values.
5. Twelve timers and 3 UARTs.

iii. *GSM/GPRS*: - This block consists of the GSM module, the UART link to the microcontroller and the SIM connector. The ESD protection for the same is also provided. Decoupling capacitors are also used to give protection to the module [18].

iv. *Interfaces and sensors*: - The USB to serial interface, anti-tampering switch, link for thermistors and for programming are given in this block. These interfaces are needed for programming of the microcontroller and also for the USB link which is useful for initial installation of the system onto the tank.

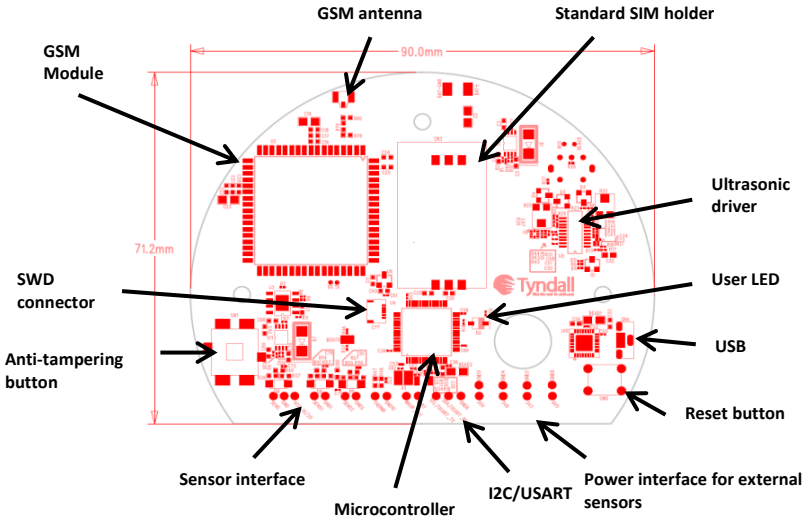


Figure 4. Placement of various components on the PCB (version 2)

2) Enclosure

An enclosure was designed with SolidWorks to make sure that the system is placed surely and safely without any external interference. Units were manufactured from Accura 25 plastic stereolithography (SLA) prototyping polymer. The Accura 25 is a white resin with the look and feel of moulded polypropylene. The enclosure is also provided with the necessary mechanisms which can make it fit into the tank.



Figure 5. System Enclosure, lower half with PCB placed

Figure 6 shows a block diagram of the system hardware

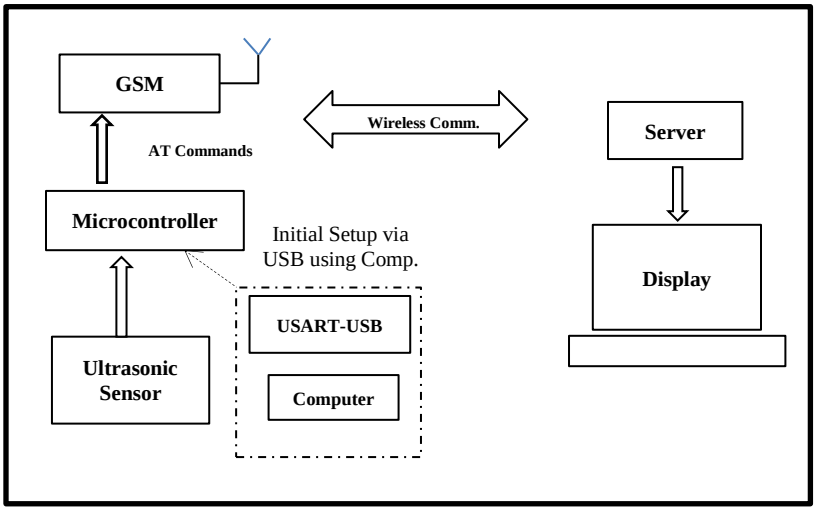


Figure 6. Block diagram of the system.

PCB Final Design .

The module was re-designed to overcome some disadvantages which were encountered in the first version of the PCB. The new version reduces the number of assembly steps, which were used.

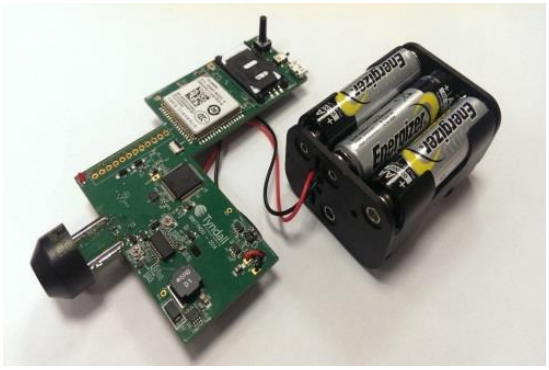
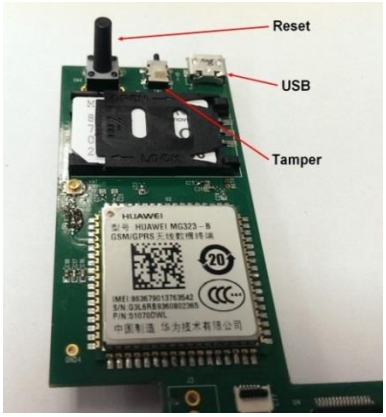


Figure 7(a). PCB Final Design



(b) The assembly of the board inside the enclosure.



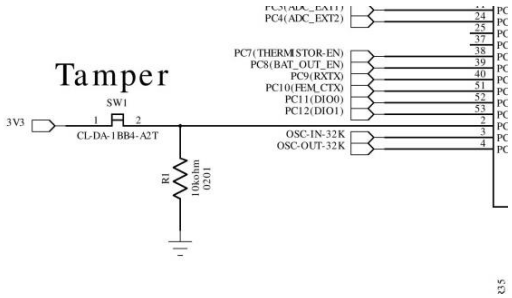


Figure 8(a). Image depicting the reset,USB and Tamper portions of the board. (b) Circuit diagram of the Tamper Switch.

On the top part of the board (close to the USB connector) there is a tamper button. This button detects if the cover of the device is open. This function is needed in case the device needs to activate special functionalities or transmit an alarm.

a.ii. Software

The software is written in embedded C. The STM32 microcontroller was programmed using a GCC Compiler based integrated development environment and the ST Link debugger was used to program the controller. The system would initially set up with the ultrasonic sensor, the ADC module, the USART channel all connected to USB via the USB to UART converter and then another USART to the GSM module. The AT commands are used to communicate to the GSM module. The system enters the GPRS mode and tries to connect to the host whose IP address and the port of access is provided during the initial setup. Then, as and when it connects to the host

server, the server would send the initial setup configuration to the microcontroller in the tank and is received via GSM module. This generally would contain the current time, the wake up time, the higher and lower threshold with respect to temperature and other concerned parameters [19]. Then the microcontroller would set the real time clock, which is one of the internal modules of the microcontroller, to the value given. The wakeup time is stored in the memory and the system would take the readings at every wake time interval and then would connect to server as and when there is a change in the threshold or once a day with the former taking higher priority [14]. This would actually help in keeping track of the sudden and unexpected variations in the liquid level thereby help in monitoring in real-time data. The server has control over the nodes and can request the information as and when needed. The flash memory which is a part of the microcontroller stores the values and is retrieved by the software code as and when needed. It can also request the memory which contains the log data to be cleared. The whole system can reboot itself as and when instructed by the server thereby helping in easy maintenance without any hassle.

Frame of Data

The data sent has the following parameters. They are:-

"Type of packet, the status and other info."

This is a standard packet which is sent to the server and an acknowledgement would be received from the other end [20]. This data is sent via TCP/IP socket using AT Commands.

IV. SOFTWARE DESIGN /FLOWCHART

The flow of logic starts when the on-board system connects to the server. The first few steps include authentication of the node and then the server sends the configuration information. Then the microcontroller takes readings, stores them and sleeps. It wakes up, takes readings and then re-connects to the server. The overall system then runs according to the server request. The server may request for a data upload or for the sensors to read the data. When the server gets the required data, it would instruct the on-board microcontroller to go to sleep.

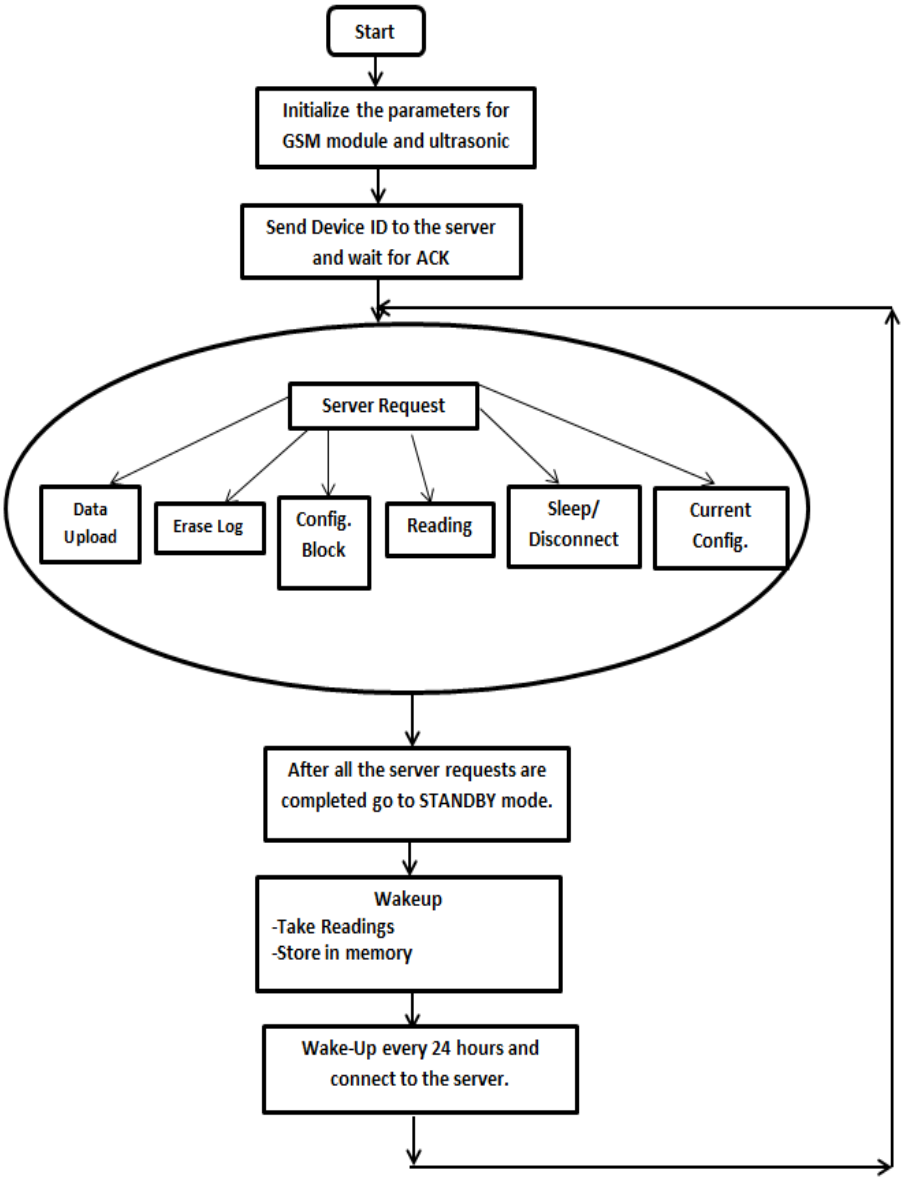


Figure 9. Flowchart.

The flowchart depicts the flow and the various modules in the program flow according to the server request. These requests need to go through various layers as shown in Figure 10.

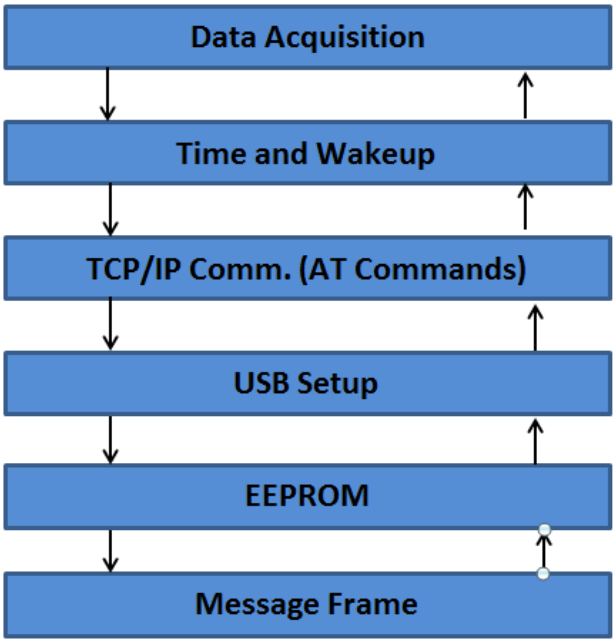


Figure 10. Layers of Communication

The various layers of communication are explained as follows:-

1. Data Acquisition: - This layer contains statements which instruct the microcontroller to acquire data like temperature and battery status through the analogue to digital convertor and the ultrasonic sensor by sending the signal to the sensor.

i. ADC:- The analogue to digital converter module is used to take values from various external peripherals and convert them to digital values which would be easily understood by the microcontroller. Resolution of the ADC is 12 bits and the numbers of channels are 16, out of which two are used. Channel number 12 of the ADC is used to get the battery status. The value is measured and stored in the flash. The battery status is most crucial because the system developed is designed to work in low power and the value stored and transmitted to the server would be useful in assessing the performance over a large period of time.

Temperature inside the tank is also crucial information that needs to be acquired. Different types of liquids have different reactions to environmental changes and when placed in an enclosed environment tend to behave in a different manner. If there is a sudden change in the temperature this would certainly indicate activity inside the tank which might be dangerous and needs to be monitored.

2. Time and Wakeup:-

The Real Time Clock (RTC), which is an internal peripheral of the microcontroller unit, is used to wake up the system from standby mode. This clock is controlled by registers in the microcontroller and can be used to keep count of the time. When the server sends the initial configuration information containing the present time; the RTC gets set and starts running until it encounters the wake-up time (which is again given in the initial configuration information). This would be running even when the microcontroller is in standby-mode; which is the lowest power mode of the microcontroller. The date is also an important quantity which needs to be updated and is done by the software code written for the same. The leap year, the numbers of days of the month are updated accordingly. This makes the system versatile and long-lasting without any need for software or hardware updating.

3. TCP/IP Communication [21] (AT Commands)

The GSM Modules receives instructions from the microcontroller. AT Commands are used to instruct the GSM to connect to the server whose IP address, socket number and other related information is provided during the time of installation of the system on top of the tank.

4. USB Setup

The installation of the system inside the tank is done by using link connect to laptop or a desktop. This is achieved by using the USB to UART Converter module. This interface connects to the UART pin of the microcontroller and channels the data received through the USB link to the controller.

5. EEPROM

The flash memory is used to store the values which are determined through other software modules. The EEPROM is emulated through software code from the flash memory of the microcontroller. The values from the EEPROM are retrieved back and used to create message frames and then this is sent to the server from the GSM module.

6. Message Frame.

The message frames are created as per server request through the software module, wherein each

value is retrieved from the flash memory and then the status frame is created and is sent to the server. The message frames can be constructed only when requested by the microcontroller; thereby would work only when active thereby reducing the power consumption.

V. LOW-POWER MODE/ENERGY EFFICIENT MODE

The microcontroller has different low-power consumption modes. They are stop mode, sleep mode and standby mode [22]. Standby mode draws lowest current which can be as low as 1.7 µA [23].

a. Power states

We can distinguish three different power states during the operation of the tank monitor:

1. The board is in standby.
2. The board performs a sensor reading (no GPRS communication) – Data Acquisition Mode
3. The board performs a sensor reading and connects to the Server - Data Acquisition and Transmission

The following table illustrates the current consumption involved for each of this states.

Table 1. Current Consumption of hardware modules.

	Stand By Mode	**Data Acquisition Mode**	**Data Acquisition and Transmission**
3V LDO	0.0014mA	0.0014mA	0.0014mA
MCU STBY	0.0034mA	12mA	12mA
3V8 DC-DC STBY	0.0055mA	0.0055mA	0.290mA
Ultrasonic	0	14mA	14mA
9V5 DC-DC STBY	0.002mA	1.5mA	1.5mA
GPRS	0	0	460mA
TOTAL	0.0123mA	27.5069mA	29.18875mA

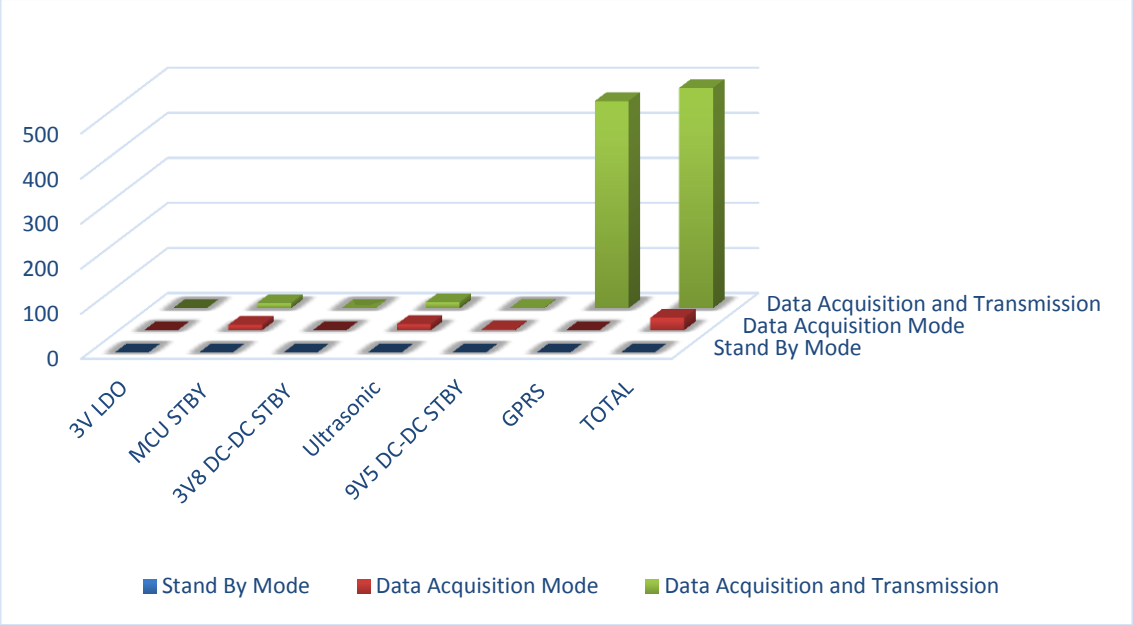


Figure 11. Graph of power Consumption.

a.1. Duty cycles of the three states

Stand-By Mode will be on all the time whereas Data Acquisition Mode and Data Acquisition and Transmission will be active only a few times per day. We consider the following situation;

- Sensor reading only = 24 times per day -> once per hour for 4 seconds
- Sensor reading and connection = once a day for 15 seconds

b. Testing

Mode of Testing: Debug Mode. When the tamper switch is pressed, it goes to the debug mode. An Agilent N6715B DC power analyzer is used to check current drawn by the unit in different modes of operation.

b.1 Test Results

Figure 12 shows the typical setup and results for testing the various power modes via the Power Analyser. The red and the black probes, are connected to the regulator on the board which in turn powers all the modules on the board. This will be the same in all 3 modes. However, in debug mode, an LED is switched ON during Data Acquisition and takes up apporoximately 10mA. This is not ON in normal working mode and has to be subtracted from the total for that mode only.

Figure 12 shows a picture during Data Acquisition and Transmission. The voltage values is 6.1202 V and the current drawn is 85.99mA.

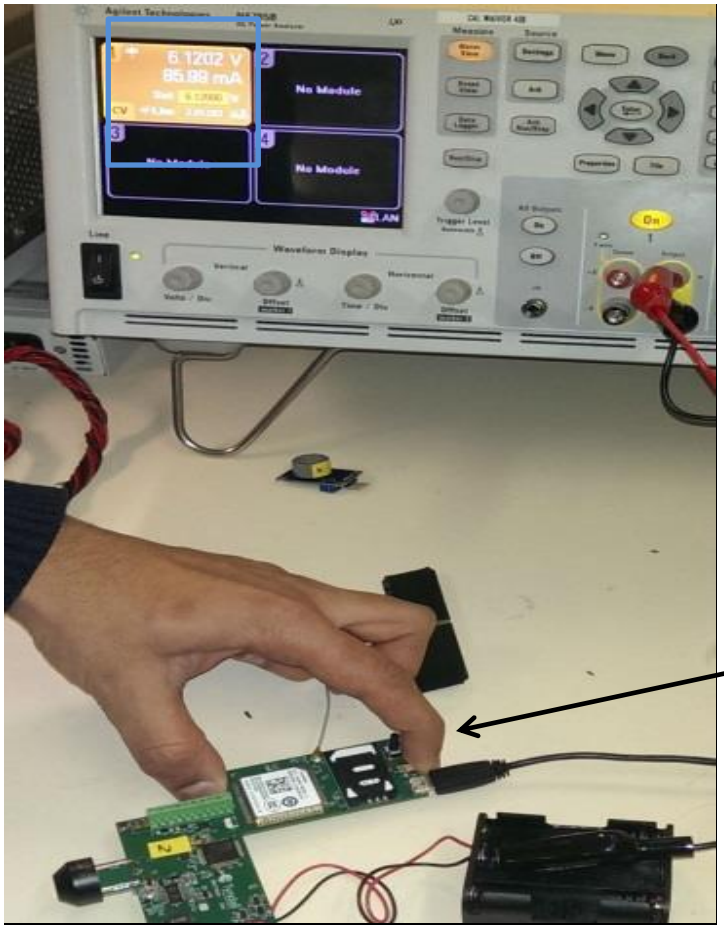


Figure 12. Power Testing Setup.

The following table gives the average total power consumption of each state:

Table 2. Current Consumption of hardware modules.

Stand By Mode	**Data Acquisition Mode**	**Data Acquisition and Transmission**
7.9uAh	46.17mA	86mA

- Sensor reading only = 24 times per day -> once per hour for 4 seconds = 59.19uAh
- Sensor reading and connection = once a day for 15 seconds = 22.9 uAh

1) Total current consumption and battery life

In total, we would have a total current drain of ~82uAh. The unit uses 6 AA batteries, which will provide 9V and considering these batteries have 1500mAh current rating, the unit has 762 days of autonomy.

The battery market has a wide variety of batteries that can perform better than that. For example the Energizer Ultimate Lithium can deliver 3000mAh and in this case we would have > 1500 days of autonomy.

2) Battery life time test

A hardware reliability test has shown that the above calculations are worst case scenario and that in a normal case the battery life time should be much longer.

VI. CONCLUSION

A low-power wireless liquid monitoring system using ultrasonic sensors was developed. The system was tested and found to be running as expected. The features of the microcontroller were utilized to build an efficient system which was both low-power and was easy to maintain. The installation of the system is easy and makes it more compatible for different environments. The GSM module ensures that the accessibility of the network can be made use of making it more reliable for users. Enabling microcontroller low power modes and restricting transmissions to once a day, or when a trigger is activated, saves the power, extends battery life and ensures a system lifetime of > 2 years.

References

[1] K. B. Dalci, K. Gulez, and T. V. Mumcu, “The Design Of The Measurement Circuit Using Ultrasonic Sound Waves For Fuel Level Of Automobile Tanks And The Detection Of Bad Sectors Of Tank By Neural Networks”, *Proc. SICE 2004 Annual Conference*, pp. 1056–1060, Sapporo, Aug 4-6, 2004.

[2] S. Ma, “Oil tank system for automatic measurement and stocktaking,” *2011 Int. Conf. Electr. Inf. Control Eng.*, pp. 1502 - 1505, Wuhan, April 15-17l, 2011.

[3] Jia Song et al., " The Industrial Tank Level Monitoring System Design", *Applied Mechanics and Materials*, 513-517, 4080, 2014

[4] Z. Minghui, Q. Xiaolong, and C. Yejin, “Low power consumption wireless temperature and humidity monitoring node based on MCF51QE128,” *IET Int. Commun. Conf. Wirel. Mob. Comput. (CCWMC 2011)*, pp. 196–200, Shanghai, Nov 14-16, 2011.

[5] I. Science and T. Mura, "A Novel Integrated Wireless Sensor Network," *Int. J. Smart Sens. Intell. Syst.*, vol. 2, no. 2, pp. 309–328, 2009.

[6] M. Assaad and I. Yohannes, "Design and Characterization of Automated Color Sensors System," *Int. J. Smart Sens. Intell. Syst.*, vol. 7, no. 1, pp. 1–12, 2014.

[7] P. Xiaohong, M. Zhi, and L. Riyao, "Traffic Signal Control for Urban Trunk Road Based on Wireless Sensor Network and Intelligent Algorithm," *Int. J. Smart Sens. Intell. Syst.*, vol. 6, no. 1, pp. 352–367, 2013.

[8] P. Sridhar and A. Madni, "Scalability and Performance Issues in Deeply Embedded Sensor Systems," *Int. J. Smart Sens. Intell. Syst.*, vol. 2, no. 1, pp. 1–14, 2009.

[9] S. Reza, S. Tariq, and S. Reza, "Microcontroller based automated water level sensing and controlling: design and implementation issue," *Proc. World Congr. Eng. Comput. Sci.*, vol. I, 2010, WCECS 2010, October 20-22, 2010, San Francisco, USA

[10] N. Giannoccaro and L. Spedicato, "Ultrasonic Sensors for Measurements of Liquid Level, Volume and Volumetric Flow in a Tank," *Precis. Instrum. Mechanology*, vol. 1, no. 1, pp. 1–6, 2012.

[11] R. Barani and V. Jeya, "Oil Well Monitoring and Control Based on Wireless Sensor Networks using Atmega 2560 Controller," *Int. J. Comput. Sci. Commun. Networks*, vol. 3, no. 6, pp. 341–346, 2013.

[12] B. Reddy and P. Eswaran, "Metro overhead tanks monitoring system using ZigBee based WSN," *Proc. IEEE Conf. Information Commun. Technol.*, pp. 367–371, JeJu Island, April 11-12, 2013.

[13] Z. Wenzheng, "Design and implementation on wireless power meter system based on GSM network," *Proc. 2010 Int. Conf. Comput. Mechatronics, Control Electron. Eng.*, pp. 76–79, Changchun, China, Aug 24- 26, 2010.

[14] L. Hongju, L. Rongchang, W. Qingzhu, M. Jiwei, and L. Jinhua, "Design of Remote Supervisory System of Large-scale Oil Tanks Based on ASP," *2009 WRI Glob. Congr. Intell. Syst.*, pp. 577–581, Xiamen, May19-21, 2009.

[15] M. Meribout, A. Al-naamanyl, and K. Al-busaidi, "Design and Implementation of a new Non-radioactive Remote Oil Tank Monitoring System", *Proc. 12th IEEE International Conference on Electronics, Circuits and Systems*, pp. 1-4, Gammarth, Dec 11-14, 2005

[16] S. Kim and H. Kim, "Systematic Optimal Design of Overlapped Ultrasonic Sensor Ring for High Performance Obstacle Detection", *Proc. 15th International Conference on Advanced Robotics*, pp 600-605, Tallinn, Estonia, June 20-23, 2011.

[17] I. AlMohimeed, H. Turkistani, and Y. Ono, "Development of wearable and flexible ultrasonic sensor for skeletal muscle monitoring," *Proc. 2013 IEEE Int. Ultrason. Symp.*, pp. 1137–1140, Prague, Jul. 21-25, 2013.

[18] Y.-W. Bai, L.-S. Shen, and Z.-H. Li, "Design and implementation of an embedded home surveillance system by use of multiple ultrasonic sensors," *IEEE Trans. Consum. Electron.*, vol. 56, no. 1, pp. 119–124, Feb. 2010.

[19] J. Xiao-yu, L. Zhong-xuan, C. Zuo, P. Chuang, and Z. Yu, "Design and implementation of MCU and the Internet communication system based on GPRS," *Proc. 2011 Int. Conf. Mechatron. Sci. Electr. Eng. Comput.*, pp. 319–321, Jilin, China, Aug. 19-22, 2011.

[20] J. Wei, X. Peng, and H. Wang, "Design of an Oil Tank Measurement and Control System Based on LONWORKS Technology," *2012 Int. Conf. Comput. Distrib. Control Intell. Environ. Monit.*, pp. 232–235, Hunan, China, Mar 5-6, 2012.

[21] F. Yanan, "Real-time Health Information Acquisition and Alarm System Based on Bluetooth and GPRS Communication Technologies," *2006 IEEE Int. Conf. Syst. Man Cybern.*, pp. 4717–4721, Taipei, Taiwan, Oct. 8-11, 2006.

[22] R. K. Megalingam, S. P.S., D. Soman, J. P.a., and S. S., "Low Power Microcontroller Based Simple Smart Token Number Display System," *2009 Fifth Int. Conf. MEMS NANO, Smart Syst.*, pp. 171–175, Dubai, UAE, Dec. 28-30, 2009.

[23] H. F. Rashvand, A. Abedi, J. M. Alcaraz-Calero, P. D. Mitchell, and S. C. Mukhopadhyay, Wireless Sensor Systems for Space and Extreme Environments: A Review, IEEE Sensors Journal, Vol. 14, No. 11, November 2014, pp. 3955-3970.

[24] C. Gonzalez, "Wireless Sensor Node: monitoring low-rate phenomena using a low-power RF-enabled microcontroller", *Proc. 2007 IEEE International Symposium on Intelligent Signal Processing*, Alcala de Henares, Oct. 3-5, 2007.