

Remote Measuring of Flow Meters for Petroleum Engineering and Other Industrial Applications

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Abstract

Reliable remote measuring of flow meters for the petroleum gas industry is proposed in this work. The monitoring of flow rates and the total amount of the fluid flow is collected using a manual process. The main goal of this work is to implement a mechanism that avoids human error and achieves reliable, continuous, and accurate monitoring. We employed the NuFlo Measurement System Model MC-II Flow Analyzer to prototype our monitoring mechanism for measuring the liquid flow and a Crossbow Technology MICA2 mote and MDA300CA Data Acquisition Board to transmit collected data via a Wireless Sensor Network (WSN). The flow analyzer generates a pulse signal whose frequency depends on the flow rate. The mote is used to count the number of pulses and send it to the host computer. An amplifier lets the mote detect the voltage level differences and overcome signal weakness. The host computer stores the data received from the mote into a PostgreSQL database for use in preparing Excel sheets and graphical displays in real time. The flow rate and the total flow amount collected by the host computer match those shown on analyzer. The design and implementation of our prototype serves as a proof of concept of how existing analog sensors used to monitor the flow rate and volume of the oil and water in petroleum production can be integrated with other devices in a WSN.

1. Introduction

Smart environments represent the next evolutionary development step in building, utilities, industrial, home, shipboard, and transportation systems automation. Like any sentient organism, the smart environment relies first and foremost on sensory data from the real world. Sensory data comes from multiple sensors of different modalities in distributed locations. The smart environment needs information about its

surroundings as well as about its internal workings. The challenges in the hierarchy of sensor system include detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating data information, formulating meaningful user displays, and performing decision-making and alarm functions. Information needed by smart environments is provided by distributed wireless sensor networks, which are responsible for sensing as well as for the first stage of the system processing hierarchy.

TETRA Technologies, Inc. (TETRA) is a geographically diversified oil and gas services company focusing on well completion and on late-life production enhancement and decommissioning. One of the basic quantities measured in petroleum production and testing is the volumetric flow thought the production pipelines. A common device used to measure the volumetric flow rate determines its reading by utilizing the linear relationship between the rotational frequencies of the turbine and the linear flow rate over a specified range of flow values. The NuFlo Measurement System's Model MC-II Flow Analyzer is adapted as our target device.

A Crossbow Technology MICA2 mote is employed to send the flow rate from the flow analyzer to the host computer. It functions as a base station when the mote is connected to a standard PC interface or gateway board. The MIB510CA/MIB520CA is a serial/USB interface device used for both EE/PROM programming of the mote and data communications. Crossbow Technology also offers the MIB600CA stand-alone unit as a gateway solution for TCP/IP-based Ethernet networks.

The MTS series of sensor boards and MDA series of sensor/data acquisition boards are designed to interface with Crossbow's MICA, MICA2, and MICA2DOT family of wireless Motes. There are a variety of sensor boards available, and the sensor boards are specific to the MICA, MICA2, or MICA2DOT board. The sensor boards allow for a range of different sensing modalities as well as interfacing to external sensors via prototyping areas or screw terminals [2].

Our main task was to integrate the Flow Analyzer with the Mote transmitter on the transmitter side and to integrate the Mote receiver with the host computer on the receiver side. The first step was to examine the output of the flow meter to simulate it in our test bed. We used the water tap to create a flow through the turbine flow meter and measured the electrical output from the flow meter. We determined that the device was generating an output that is a 200 mV peak-to-peak sinusoidal signal whose frequency depends on the flow rate. A function generator in our laboratory was used to simulate the turbine flow meter by generating a similar signal as the turbine. This signal was input into the MC-II Flow Analyzer. The second step was to figure out how to properly acquire the flow rate signal from the flow meter. Our initial approach was to intercept the value from the flow meter circuit before it was displayed on meter's LCD display. This approach was rejected due to the additional load placed on the circuit.

We finally decided to use the pulse output signal generated by the MC-II Flow Analyzer; it is a 1 V pulse signal. Due to the weakness of the pulse signal, it was required to amplify it to a level that could be detected by the mote. The flow meter's totalizer firmware can be configured to scale the volume increment used for the pulse on the amount using from 1.001 units to 100.00 units. The third step was to connect the output pulse to the mote in order to send the total volume wirelessly to the host computer. The last step is to receive the data on the host computer from the motes in the sensor network and store the incoming in a PostgreSQL database for use in preparing analysis spreadsheets and graphical displays in real time.

2. TETRA Technologies, Inc.

TETRA holds premier market positions in several niche oil and gas service market categories, including: completion services, well abandonment and decommissioning, production testing, and compression-based production enhancement. Production testing of oil wells requires the collection and analysis of fluid flow rates and composition. Figure 1 shows the design of TETRA's oil well testing equipment. Crude oil is diverted from the well head production pipeline into a set of oil, gas, water, and sand separators. The overall production quality of the well is measured by comparing the ratios of gas, water, and sand to the amount of oil flowing from the well. The prototype discussed in this article is concerned with only oil and water flow meters.

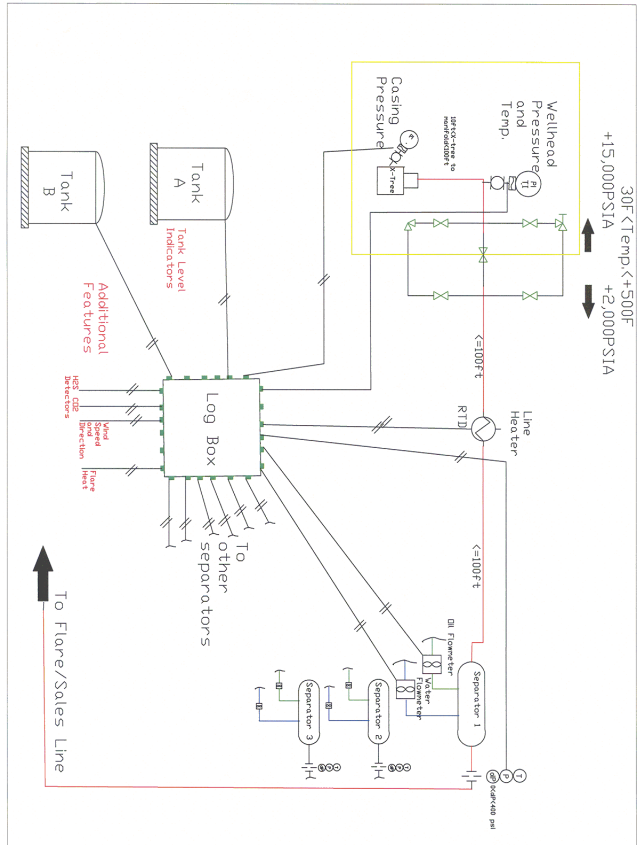


Figure 1. The TETRA Requirements.

3. MC-II Flow Analyzer Specifications

The NuFlo Measurement System's Model MC-II Flow Analyzer receives an electronic pulse stream from a turbine flow meter and provides a registration of the totalized flow and an indication of flow rate by utilizing its microprocessor-based circuitry. The totalized flow and the flow rate are displayed on two six-digit liquid displays (LCD's). Both displays are properly labeled with respective measurement units. The low current draw of its CMOS microprocessor-based circuitry permits MC-II to run for three to five years on single battery. MC-II has the advantage of being battery powered and enclosed in non-corrosive weatherproof housing, deemed ideal for use in remote locations [3] [4].

Totalizer readings can be made in any desired volumetric units and flow rates can be measured in units per second, minute, hour, or day. Rate and total readings can be quickly and easily calibrated using the keypad on the front of MC-II. The unit can be mounted directly on the turbine meter or be attached remotely. Figure 2 shows the MC-II Flow Analyzer.

The NuFlo Measurement System Model MC-II Flow Analyzer has the following characteristics [3]:

- Size: 7.3" (wide) x 8.3" (high) x 3.4" (deep)
- Weight: 6 lb including shipping container
- Power supply: One 3.6 volt lithium battery
- Current consumption: 200 microamps typical
- Temperature range: -40 to +140°F
- Totalizer and flow rate display: six digits
- Divisor or calibration factor range: 0.001 to 999,999
- Standard units: bbl and bpd (other units available)
- Accuracy: ± 1 count (totalizer)
- Input frequency: 0 to 3,500 Hz
- Input amplitude: 30 to 3,000 mV peak to peak



Figure 2. The MC-II Flow Analyzer.

4. MICA2

The MICA2 Mote shown in Figure 3 is a third generation mote module used for enabling low-power, wireless, and sensor networks. The following features make the MICA2 a good choice for commercial deployment [2]:

- 868/916 MHz, 433 MHz or 315 MHz multi-channel transceiver with an extended range
- TinyOS Distributed Software Operating System v1.0 (TinyOS), with a networking stack optimized for WSNs and improved debugging features
- Support for wireless remote reprogramming
- Wide range of sensor boards and data acquisition add-on boards

TinyOS is a small, open-source, and energy efficient operating system developed by UC Berkeley to support large scale, self configuring sensor networks. Its source code and software development tools are publicly available [5]

4.1 Sensor Boards

Crossbow offers a variety of sensor and data acquisition boards for the MICA2 Mote. All of these boards connect to the MICA2 via the standard 51-pin expansion connector. Custom sensor and data acquisition boards are also available.



Figure 3. Crossbow Technology MPR400CB Mote.

5. Processor and Radio Platform

The Processor and Radio Platform (MPR400CB) are based on the Atmel ATmega128L. The ATmega128L is a low-power microcontroller, which runs TinyOS from its internal flash memory. Using TinyOS, a single processor board (MPR400CB) can be configured to run sensor applications/processing and the network/radio communications stack simultaneously. The MICA2 51-pin expansion connector supports Analog Inputs, Digital I/O, I2C, SPI and UART interfaces. These interfaces make it easy to connect to a wide variety of external peripherals, as depicted in Figure 4.



Figure 4. Crossbow Technology MDA300CA Data Acquisition Board.

Connection of analog devices and other industrial sensors to the MPR400CB is supported by MDA300CA Data Acquisition Board (DAQ). The combination of a MICA2 mote and a MDA300CA implements a low-power wireless data acquisition device or process control machine. Analog sensors can be attached to different channels based on the expected precision and the dynamic range. Digital sensors can be attached to the provided digital or counter channels. The mote samples analog, digital or counter channels and can actuate via digital outputs or relays. The high-resolution digital counter channel on the DAQ is used to count the number of pulses coming from the MC-II flow analyzer, the counter channel is used. Table 1 below gives the absolute maximum ratings for various electrical parameters for the MDA300CA [6].

Table 1. The MDA300CAs Absolute Maximum Ratings

+VDD to GND	-0.3V to +5.5V
Digital Lines	
Input voltage range	-0.5 V to VDD + 0.5 V
Continuous output low current	50 mA
Continuous output high current	-4 mA
Analog Lines	
Input voltage range	-0.2 V to VCC + 0.5 V
Counter Line	
Input voltage range	0 V to 5.5V

6. Amplifier circuit

The flow rate signal coming from the flow meter is very weak so the Mote could not detect it. An amplifier circuit is designed to amplify the flow rate signal from 1V to 2.5V. An LMC6484 CMOS quad rail-to-rail input and output Op-Amp is used in the amplifier circuit. LMC6484 provides a common-mode range that extends to both supply rails. This rail-to-rail performance combined with excellent accuracy, due to a high CMRR, makes it unique among rail-to-rail input amplifiers. It is ideal for systems, such as data acquisition, that require a large input signal range. Maximum dynamic signal range is assured in low voltage and single supply systems by the LMC6484's rail-to-rail output swing. The LMC6484's rail-to-rail output swing is guaranteed for loads down to 600Ω. Guaranteed low voltage characteristics and low power dissipation make the LMC6484 especially well-suited for battery-operated systems. Figure 5 shows the schematic diagram of the amplifier circuit we designed and Figure 6 illustrates the layout diagram of the amplifier circuit.

The gain of the circuit is calculated using Eq. (1), so the values of Resistors R1 and R2 are 10K and 15K, respectively:

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1} \quad (1)$$

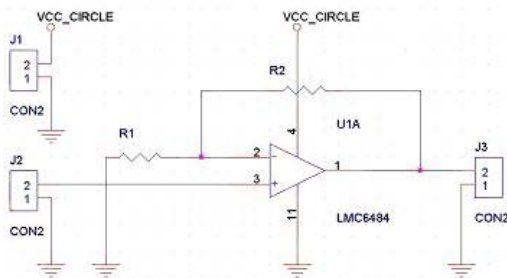


Figure 5. Schematic diagram of our amplifier circuit.

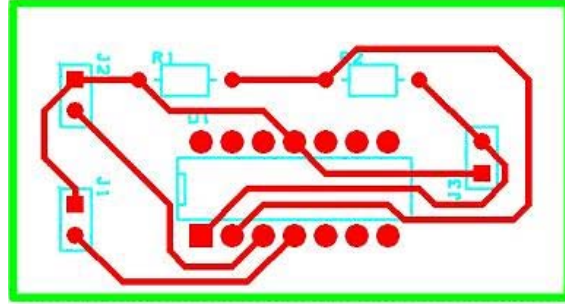


Figure 6. Layout diagram of our amplifier circuit.

7. Experimental results

The amplifier circuit and the Mote package are mounted inside the flow meter itself as shown in Figure 7. The MC-II Flow Analyzer's battery feeds the amplifier circuit as well. The amplifier circuit consumes 1 mA, the same as that of Flow Analyzer, so the life time of the battery will now be one half of the original life span. As mentioned in the flow meter manual that the battery life time is 3 – 5 years, our prototyped flow meter as a whole will last for 1.5 – 2.5 years using its original battery. The experimental tests show that the prototyped system works well if the flow meter and the host computer are within 55 feet apart.

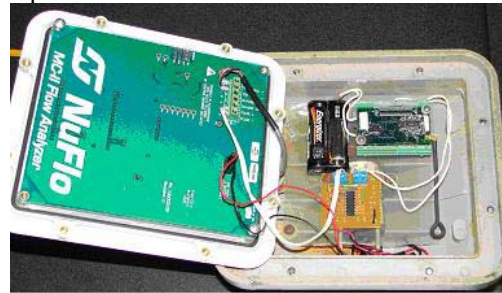


Figure 7. Our prototype.

A sample of the data collected from the flow meter is shown in Figure 8. The data is updated from the PostgreSQL database on a periodic basis and input into the correct fields in TETRA's well field data spreadsheet shown in Figure 9. This information is automatically transferred to the data sheets used to report well performance to TETRA's clients.

8. CONCLUDING REMARKS

A reliable prototype of a remote measuring flow meter for petroleum field application is implemented and tested. The received data is stored in a PostgreSQL database for later use in well

