SMART WATER-METERING APPROACH WITH DIAGNOSIS FOR DETECTION OF CONSUMER SIDE-LEAKAGE, TAMPERING AND OTHER FAILURES

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ABSTRACT
Smart water-meters have been around for more than two decades but have not generated mass appeal among consumers and utilities in most third-world countries. The reasons perceived are higher meter costs compared to conventional meters, lack of Open non-proprietary protocols for Communication and ITES, seemingly very low benefits to cost ratio, etc. which are all potential barriers to adoption of smart-metering. Generally, smart-metering have not found favour beyond remote reading using handhelds.

This paper discusses a smart-metering approach that promises numerous advantages to both utilities and consumers such as a host of fraud-detection/ tampering and meter-malfunction identification mechanisms, consumer-side leak detection and warning, etc. Some of the proposed diagnostics for the low-cost implementation are also discussed in the paper.

The hardware and software approach to implementing a low-cost smart-meter are detailed. The scheme proposes use of Open communications protocols including Zigbee, standard Internet broadband communications options, etc. so as to eliminate requirement for proprietary products and infrastructure to help reduce overall cost.

KEYWORDS
Smart-Meter, Diagnostics, Pulse generation, Meter-Tampering, Meter failure, Leak Detection, Communication

INTRODUCTION
Water meters are used for measuring water use and generate consumption billing. Smart water metering is a comprehensive approach to automate meter reading process including collecting data from all domestic, commercial and industrial consumers in the city in order to track, bill and manage water supply. The advantage of improved water metering include control of consumption, leak detection, fraud and manipulation detection, meter theft detection, improved secure data transfer, effective financial conversion of consumption data, etc [1] leading to better management and operations planning.

Water utilities, governments, and meter manufacturers are increasingly exploring feasibility for use of “smart” or advanced metering infrastructure [2] for present cities and future smart cities. The expected advantages include timely availability of important information such as leaks, average water usage, reduction in operating costs and improved water availability.

The smart-meters commercially available at present typically incorporate a reed-switch or hall-effect pulse generation mechanism by detecting motion of a tiny magnet embedded on a rotating wheel in the meter register. The pulse signal generated is conveyed by wire to a counter circuit that electronically counts the pulses to produce information on water consumption. The reed-switch or hall-sensor for pulse generation is typically a small attachment on the water-meter register. The inherent drawbacks in the present scheme as implemented in many commercially available water meters are

- No mechanism to detect a detachment of pulse-generation system at water-meter register
- No mechanism to detect detachment/ cut to the pulse signal cable, where sensor and counter electronics are separate units
- No mechanism to detect breakage of register unit seal and detachment of register from water meter body.
- No detection for frauds such as possible blocking of pulse generation by external means such as use of a strong magnet.
- Inability to identify /detect remotely in a timely manner, the meter failure/ tampering /frauds perpetuated such as cited above.
- Seemingly, no advantages offered to consumers compared to conventional water-meters.
- High cost of smart or AMR water-meters.
- Reliability for smart electronics, power source (battery), communications, etc. in actual field use is not assured / known from previous experience.
- High cost of battery, its useful life and replacement costs.

To overcome the drawbacks, a novel low cost approach for smart water-metering is being proposed in this paper.

1.0 SMART WATER-METER PROPOSED

The proposed novel smart-meter incorporates a number of features through both software and hardware design as discussed in this paper. The architecture of proposed smart meter comprises the following sensor mechanisms to identify and detect frauds and meter failures:

- Tamper detect sensor/switch to detect decoupling of pulse generation module
- Tamper detect sensor to detect detachment of register from meter body.
- Hall-effect sensor to detect strong external magnetic fields that prevent meter pulse generation
- Software diagnostics to identify periods of abnormal use to determine consumer side leakage, possibility of unaccounted for flow, etc.
- Diagnostics through remote module, thereby reducing hardware and intelligence overheads, battery/power needs, reduced meter costs, etc.

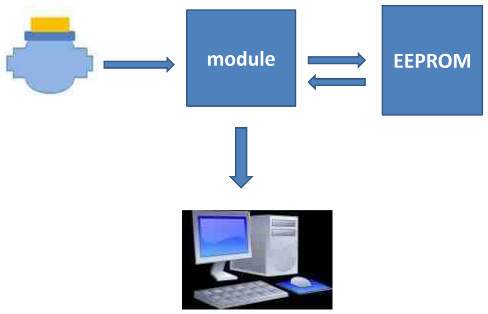

Figure 1: Data flow path in prototype system

The proposed smart-meter unit has an electronic module that is installed with meter-register. A spring-loaded micro-switch installed between meter-body and the register module acts as a register-tamper sensor. In water-meters that are manufactured with pulse-pickup reed-switch or hall-sensor as external attachment, a second micro-switch to detect repositioning or removal of pulse generation sensor is needed. However, its suggested to have the reed-switch or hall-sensor constructed within the meter-register casing so that external removal is possible only by breaking the register case.

A tiny hall-sensor to detect presence of strong external magnetic field is used to detect non-intrusive tamper / fraud targeting non-registration of pulses due to consumption. This smart module in the prototype is fixed to meter register as integral construction. A microprocessor in the module totalises flow pulses and stores consumption to non-volatile memory along with active state of tamper sensors. Conditions such as occurrence of leak at downstream of water-meter, very low flows (possible clogging or tamper) are also detected and indicated by on-board LED indicator. For the prototype, a low cost microcontroller ATMEGA328P with built-in 32K EEPROM and I^2C serial bus, etc. is used. The occurrence of tamper initiates interrupt signal for instantaneous detection. The module uses open-source software, low-cost minimal hardware and has low power consumption.

Figure 3: Electronic Interface Module *(shown to scale)*.

1.1 WORKING PRINCIPLE

The microcontroller performs a range of tasks including consumption totalising, periodic logging of consumption data into memory (once every 6 hours), and event based verification for running diagnostics.
As part of intelligence in the meter, a one-time configuration during installation requires the utility authorised personnel to select from a pre-stored water consumption pattern corresponding to one of many user profiles. Consumer profiles include the following

- Domestic consumers with usage patterns at specific time periods of the 24-hour day.
- Domestic consumers with a number of people using water throughout the day
- Hotels, restaurants and commercial establishments, where usage patterns are different from regular domestic usage.
- Periodic consumption pattern as in moderate volume Industrial use.
- Periodic consumption pattern as in large volume Industrial consumers.

During configuration at the time of installation, one of the usage patterns are selected and thereafter the actual water consumption log is used to generate an average consumption pattern based on a long period (either a 7 or 14-day log or monthly log). The diagnostics routine would periodically evaluate the consumption log and compare against the consumer usage profile to determine several kinds of information on the consumer. These include average consumption / demand during various months / seasons, occurrence of leak in meter downstream, clogging of downstream pipe, meter tampering possibility even when tamper flags are not set by the tamper switches / sensors.

Deviation from reference data by more than 25% initiates a three-day leakage detection check sub-function. If the trend persists, the LED is toggled ON to indicate a leak.

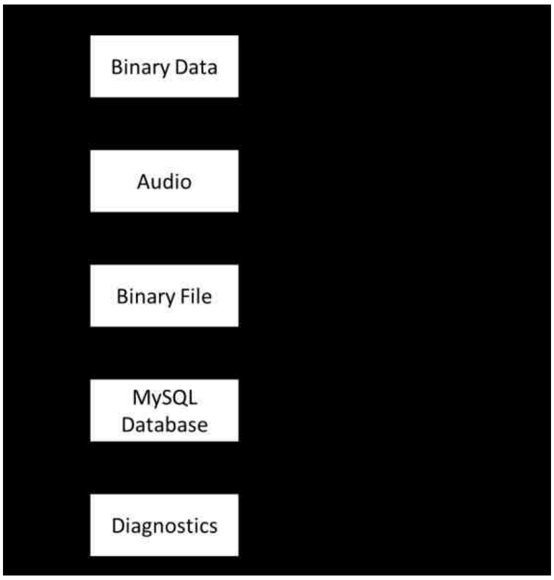

Figure 3: Data Organization and Transmission

The microcontroller has a communication port for serial data communication by FSK to transfer data to the remote monitoring device or computer. In the proposed smart-metering scheme, the communication port is interfaced to a computer through permanent cable via its audio port or through a gateway-pod designed around a *Raspberry Pi* computer. The computer in turn interfaces through Wifi / broadband / Ethernet TCP/IP into the Utility computer network.

For direct data capture to smart-phone as a handheld, either a battery powered tiny gateway unit is used in conjunction with the smart-phone or its phone jack could be directly connected to the meter. The Android smart-phone App enables data conversion, logging and analytical functions.

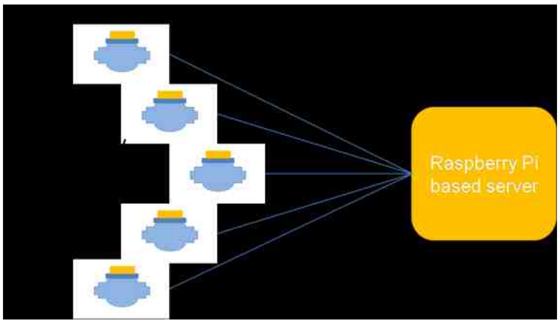

Figure 4: schematic showing water metering system in an apartment complex.

In the case of apartments and commercial complexes with a number of water-meters installed in close vicinity, the individual water meters are connected to a common *Raspberry Pi* based mini-server. This local Server processes and diagnoses data from multiple meters and communicate to the utility through cloud.

2.0 GUI AND DATABASE

For the prototype system, MySQL based database is used and programming through *Python*. The serial FSK data over audio jack is read into ASCII file and updated to respective tables in the MySQL database.

The GUI interacts with database to facilitate viewing of consumption details, reports on diagnostics, time-based usage patterns, monthly consumption, unpaid / pending Bills, etc.

The proposed scheme enables users to log in for viewing usage data and related analytics. Diagnostics include testing for loss of data from individual water-meters, battery-low failure detection, communication failure detect by pinging in case of data packet loss, etc.

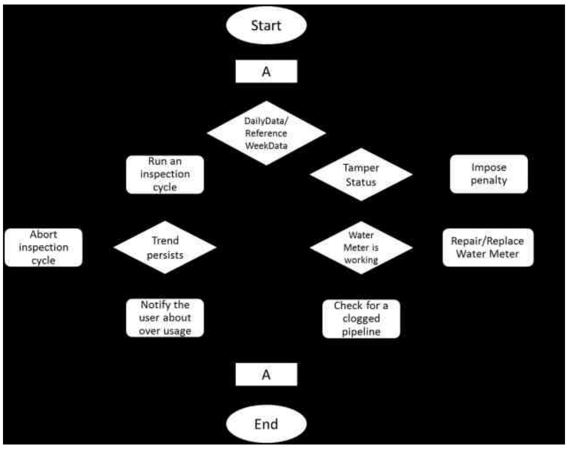

Figure 5: Flow chart for Diagnostics

CONCLUSION

The prototype smart water-meter scheme proposed refines the current architectures, details out possible diagnostics and analytics that could benefit the utilities as well as consumers, while keeping the overall cost low. The proposed architecture could be adopted by water industry as well as water-meter manufacturers in order to provide real intelligence and smart metering for both the present cities as well as upcoming smart cities.

Scaling up the proposed scheme to cover domestic and commercial piped gas-meters has large potential for cost savings on communication and ITES / database infrastructure. The proposed scheme opens up potential for third-party based metering-billing business models.

ACKNOWLEDGMENTS

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Areas of Interest:

- Multi-phase flow,
- Embedded Applications, Sensors and Mechatronics.
- Data Acquisition Systems,
- Multipath Ultrasonic Flowmetering
- Smart-metering and IIoT

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- Co-author of a Chapter in the Book: *Computerized Tomography for Scientists and Engineers* by Dr. Prabhat Munshi, CRC Press, 2007. *ISBN 9781420047936.*