Contactless Smart Card Based Prepaid Gas Metering System

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Abstract

Natural gas is one of the most important resources of energy in the whole world. It is used for domestic, commercial and industrial purpose. As the resource is limited a precaution should be taken to minimize misuses and wastage of gas. Earlier a prepaid gas meter was designed, developed and 4500 meters were installed in the customer's premises. However there were some limitations of the meters. In this paper a contactless smart card based prepaid gas meter system is presented for the domestic customers to overcome the limitations. A prototype of the system has been developed and tested. It provides higher security consumes lower power and more user friendly than the earlier version of prepaid gas meter.

Keywords
Prepaid gas meter, contactless smart card, NFC, Mifare

1. Introduction
Gas is a prominent resource of energy which is used for domestic, commercial and industrial purpose. To provide gas for non-metered domestic customers no meter is installed at the customer end. In this case customer has to pay a fixed monthly bill depending upon the number of burner he uses. As the customers pay a fixed amount independent of the uses, they pay very little attention to the misuses of gas. In some cases customers use valuable gas wastefully by drying clothes, keeping room warm or by using inefficient gas appliances. Sometimes even customers turn on their burner whole day long just to save a stick of match. Again there are some dishonest customers who indulge in gas pilferage. Prepaid gas system opens the eyes of the non-metered customers that they have to pay only for the volume of the gas they will consume and thereby an awareness not to misuse gas. It will also encourage them to save money and use the gas for useful purpose. As this system includes 2-way dataflow system, utility companies can check the vending profile along with the consumption pattern to identify any problem at the meter end take necessary actions. Now in Bangladesh no-metered customers have to pay 450 Tk. per month per double burner for whatsoever gas they use. According to the present rate of domestic gas (5.165 Tk. per cubic meter) a customer should not use gas more than 87.12 cubic meter gas. But in a survey it is found that there are a number of customers who use 110.05 cubic meter gas per month (Titas 2009). This prepaid system can eliminate this difference and make the customers aware against wastage and misuse of gas. This arrangement will eliminate the system loss incurred due to use of gas in unauthorized gas appliances. The company will not also be deprived of the revenues for any connection. In some cases at the customer end there may be gas leakage due to the problem in gas supply line which are not known by the customers or utility companies. This problem can be identified by the uses pattern of the customer and can be eliminated thereby.

Prepaid system will enable the utility company to collect revenue in advance. In current postpaid system, there are many cases where the customers' could not trace their bill. Moreover, the domestic customers' have to manually fill a bill book, go to bank and stand in a long queue. On the other hand, the bank sometimes does not send the payment information to the company. So the company tries to disconnect the customer's line due to information gap between the bank and the company. Prepaid gas metering system will help to remove all the above problems and improve customer service significantly. Utility has to engage a number of people for disconnection and re-connection of customer's line. Moreover there are always dispute, arbitration etc. between customers and the utility companies. All the above problems will be totally absent in prepaid gas metering system.

Some works have been done with smart and prepaid metering system in Khan et al. (2007), Khan et al. (2009), McConnachie (1999), Ali et al. (2008), Mohammad (2013), Kwan and Moghavvemi (2002), Gavra et al. (2012) , Cowburn (2001) and MacDonald (2009). In Khan et al. (2007), Anglani et al. (2011), Deconinck et al. (2011), Hindersah et al. (2011), Mohammad et al. (2013), Mehmood et al. (2011), Parvin et al. (2012) and Yu et al. (2010). In Khan et al. (2007) for pulse from rotating gear i.e. consumption measurement is done optically which is power consuming. Another disadvantage of this design is the valve control system which is also power hungry. These problems are solved in another design in Khan et al. (2009). Later in 2010 smart card based prepaid gas meter was designed, developed and tested in IICT, BUET for TITAS Gas Transmission and Distribution Limited, one of the famous gas utility companies in Bangladesh. Under a pilot project 4500 meters were installed two areas in Dhaka, Bangladesh. The previous meter installed in a customer's house under a shade is shown in Figure 1. As the meters are installed outdoor the shed is used to protect meters from rain. In this case each meter is used for different customers in a house. In this design contact type smart cards were used to implement prepaid system. As in this case the card has to be inserted to the gas meter the meter cannot be sealed perfectly. And sometimes dust particles block the card insertion place. As in most of the cases meters are installed outside of houses and they are vulnerable to the environment. Water and dust particle may enter the meter and damage the electronic module. The power consumption of the meter was high and it was run with four AA size batteries. These problems are carefully studied and solved in our new design. Another limitation of the previous design is that a customer is assigned to a zone and the customer can't buy credit vending station from other zones. This problem is solved by in our software design. Though in our design a customer is assigned to a zone but s/he can buy credit form any vending station from any zone which increases the flexibility of vending.

Figure 1: Previously designed prepaid gas meters installed in a house

2. Design Architecture

In this design meters will be installed at the consumers' places and the central server and database will be at utility company's secured place. For operational purpose, whole geographical area of the utility company servers may be divided into different zones. For each zone there will be one or multiple vending stations assigned for that zone from where customers can buy credits. All vending stations are connected to the central server through internet. In case of internet failure customer can buy credit in the offline mode through the same station. As soon as the vending station will be online, all credit information will be synced with the central server. This will help to increase vending flexibility. Though each customer is assigned to a specific zone, s/he can buy credit from any other zone defined in the central server. The whole design is shown in Figure 2. In the block diagram prepaid gas meter is the gas meter module installed in customer's place. A unique contactless smart card is assigned for the customer which is medium of 2-way data flow i.e. balance recharge to the gas meter and information extraction from meter for analysis purpose. Vending Station (VS) is a computer with internet facility in any place arranged by the utility company from where customer can purchase credit. System Master Station (SMS) is the central server with database server where all information is stored and processed. It is installed in a more secure location with stable internet and power facility.

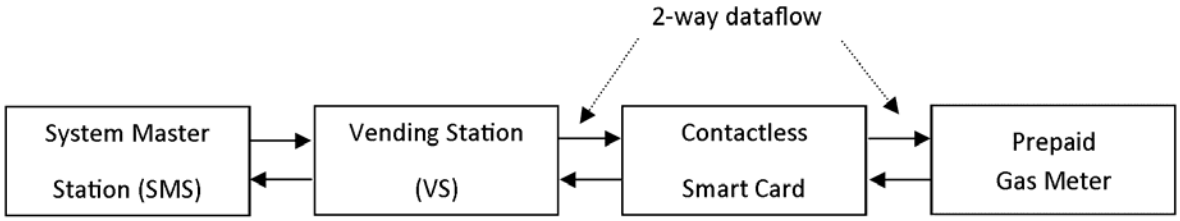

Figure 2: Contactless smart card based prepaid metering system

When a new customer requests for a gas line from utility company, first s/he is assigned a meter at customer's house and a smart card is assigned for him. Whenever customer wants to buy credit, s/he goes to any vending station and buys credits. Then s/he holds the card near the meter and meter debits that amount of credit. At the same time meter writes some information regarding meter to the card and next time customer goes to the vending station for buying credit all information from meter is transferred to the central server through vending station. With this 2-way dataflow communication the company can monitor the health of meter as well as usage of the customer.

2.1 Hardware Design

For this design a G1.6 diaphragm meter is used as a base meter and our electronic design is attached to that base meter. Electronic circuit gets pulse from the base meter through magnetic reed switches. Figure 3 shows the block diagram of our designed gas meter.

The control unit of the design is the MCU module. For the design we use ATMEGA64A, a high-performance, low-power Atmel 8-bit AVR RISC-based microcontroller combines 64KB ISP flash memory with read-while-write capabilities, 2KB EEPROM, 4KB SRAM (Atmel 2013). It has 53 general purpose I/O lines, 32 general purpose working registers, a real time counter, four flexible timer/counters with compare modes and PWM, two USARTs, a byte-oriented 2-wire serial interface, an 8-channel/10-bit A/D converter. It is a low power microcontroller which consumes low power both in active and sleep mode. This device can operate 2.2 - 5 voltage. In our case the electronic module is run with 3.5 V which is achieved by 3 AA batteries which are available everywhere in the world.

The base meter includes an electronic pulse generating system with reed switches which work magnetically. It has 8 mechanical wheels that display analog usage among which 3 wheels are for fraction. A magnetic contact is fixed with the rightmost wheel. Two other magnetic contacts are fixed with different points on the base meter with which two reed switches are connected. Whenever the contact of the wheel is near to any of the contacts of the base meter an electronic pulse is generated with the respective reed switch. For each rotation of the rightmost wheel, the base meter generates two electronic pulses alternatively. These two pulses are connected to the MCU with two interrupts. The gas meter also includes a DC brush motor which controls the valve to control gas flow. The motor is also

connected with MCU through an H-Bridge driver IC Sanyo LB1836M. MCU sends signal to the LB1836M to run the motor in desired direction.

A voltage level detector module is implemented. If the voltage level goes down below the tolerable voltage range to run the whole circuit board perfectly, MCU saves all information to EEPROM, close the valve and shut down normal operation. This module serves another important operation in case of sudden power down i.e. battery is removed from the electronic board. In that case MCU saves all information and close the valve immediately.

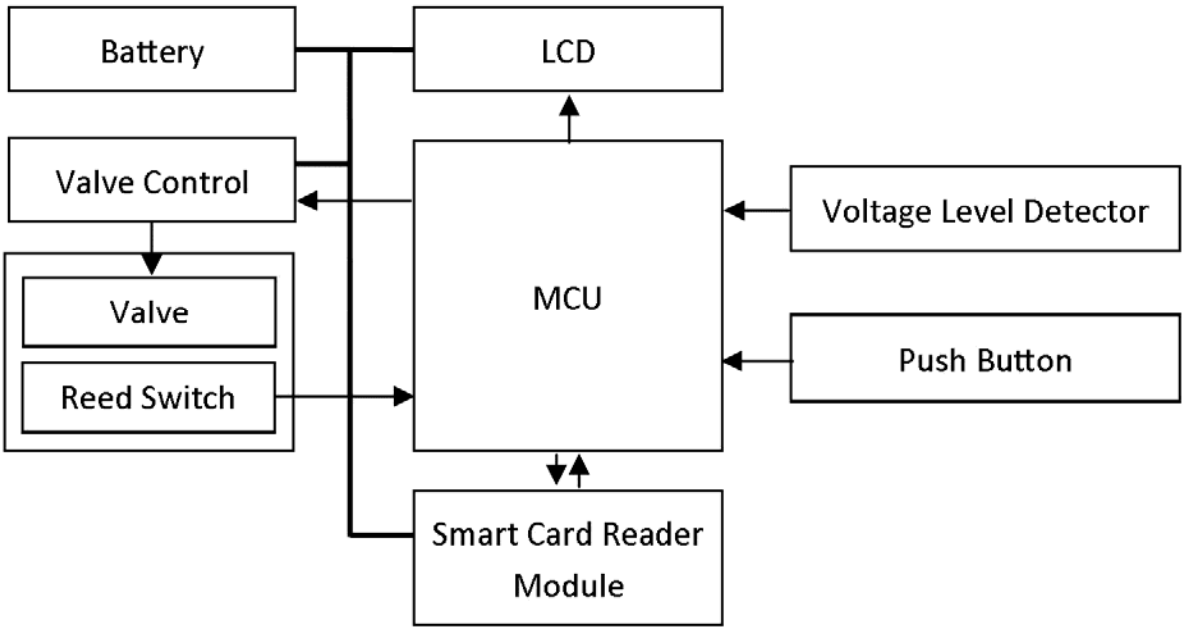

Figure 3: Block diagram of gas meter hardware design

For displaying information a graphical LCD display SED1335 is used. But for increasing power performance, the LCD is kept off in normal operating condition. Whenever customer press a switch mounted on the board, display becomes active for a certain period of time and slides different information like consumption, current balance, and active rate. It also includes icon for valve whether it is closed or open, battery and other operational information.

The smart card reader module is used to communicate with contactless smart card which uses UART protocol to connect with MCU. The prepaid system is designed with Near Field Communication (NFC) standard to communicate with the card from meter and vending station. It is based on Radio Frequency Identification (RFID) standards including ISO/IEC 14443. A serial NFC reader is used to communicate with the card from. In our design Mifare 1k card is used with the range of 6 inches. It uses contactless transmission for data and energy and no battery is required for that. Each card has a unique serial number and uses mutual three pass authentication (ISO/IEC DIS9798-2). The NFC reader module is not active all the time. When the push button is pressed, NFC module becomes active. After pressing button MCU display information through display module and at the same time it searches for valid NFC card for further operation. If customer holds the card upon the meter, MCU communicates with the card and gets the credit information and writes back the meter's health and consumption information.

Another important module is the power or battery module. The whole circuit is designed to run with 3.5V. To achieve this voltage 3 AA batteries are used. A diode is used to protect the circuit board in case of reverse voltage applied.

2.2 Firmware Design

The firmware is designed with two layers. The bottom layer is the hardware layer. In this layer for each module a separate driver is written to communicate with that module form the MCU. The upper layer is the main firmware

layer which implements the algorithm and controls the modules with the help of bottom hardware layer. Figure 4 shows the simplified flow chart of the design.

At the startup MCU loads necessary information from the EEPROM and initializes the meter and peripherals. Then it goes to SLEEP mode to reduce the power consumption. The MCU is only waked up if any interrupt occurs. Three types of interrupt which can occur are pulse interrupt, push button interrupt and low voltage interrupt. In each case MCU goes to the ACTIVE mode, operates certain actions depending upon the interrupt type and goes back the SLEEP mode again. The pulse interrupt occurs when pulse comes from any of the two reed switches. As the MCU gets two pulses from the two reed switches per revolution of the right most wheel, an algorithm is implemented to count one with two alternate reed switch pulses. If any switch gets faulty i.e. always open or always closed, pulse from that reed switch is discarded. After detecting pulse MCU count usage and deduct credit depending upon the active rate. Then it updates the valve status i.e. if balance is below the predefined threshold from the utility company, the valve is closed. MCU waits for pulse for certain period of time. If any pulse interrupt occurs within this period then it process the same counting and deducting balance procedure and also reset the waiting counter. If the waiting counter expires i.e. there is no pulse within certain period of time, MCU goes back to the SLEEP mode.

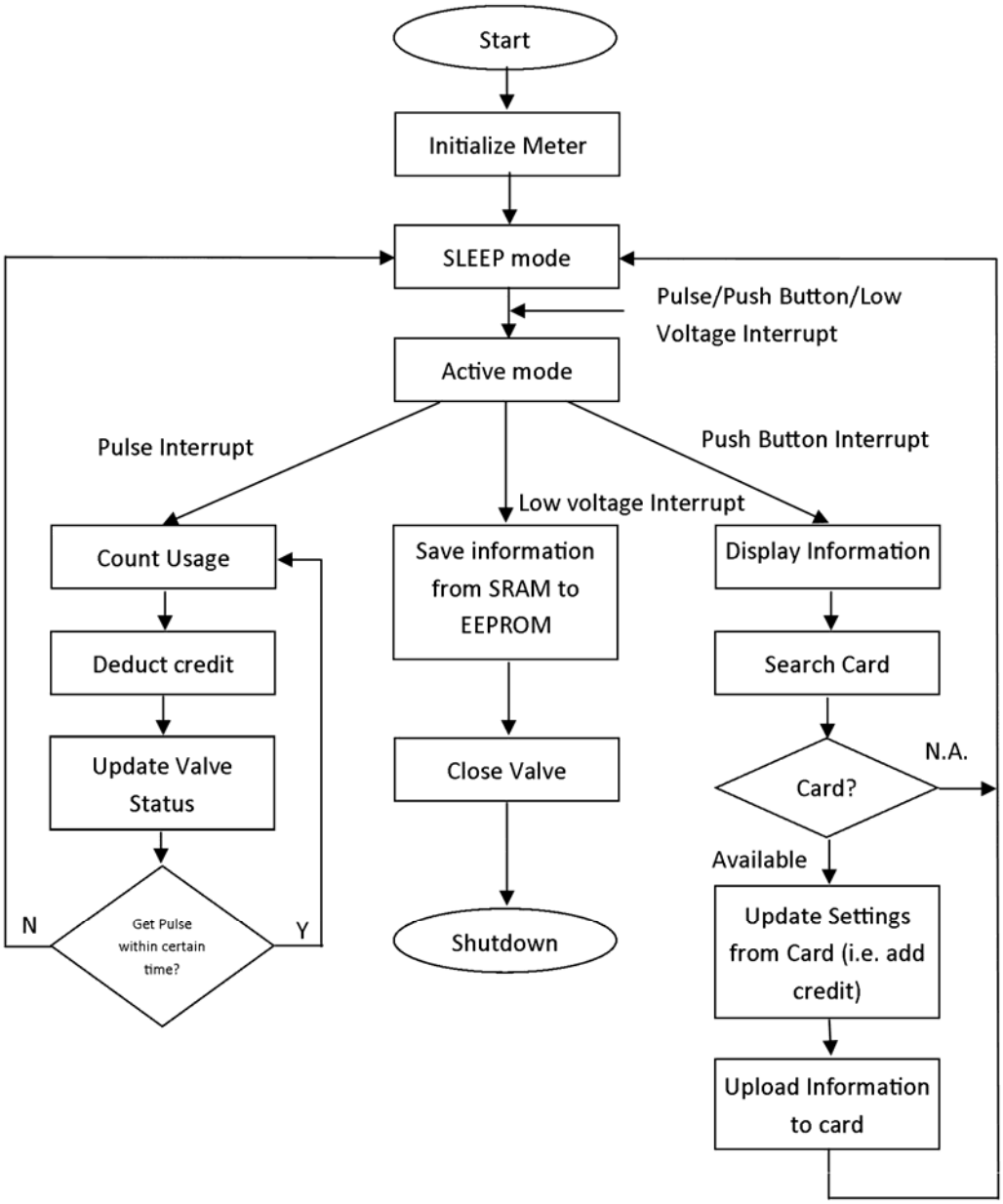

Figure 4: Flow chart of firmware design

Another reason for leaving the SLEEP mode is pressing the push button. Whenever someone presses the push button the display becomes active and shows slides necessary information like consumption, remaining balance, active rate and displays operational icons for a certain period of time. In the meantime MCU searches for valid NFC card. If MCU gets any valid NFC card, it shows a CARD BUSY icon. MCU checks the card type and takes certain action depending upon the card type like adding credit. Then MCU uploads necessary information to the card. After successful operation of the card MCU shows REMOVE CARD to indicate that the customer can remove the card. If MCU doesn't get any valid card or customer doesn't press the button within predefined time, MCU goes back to the SLEEP mode again.

An interrupt may come from the voltage level detector module. If low voltage is detected even in the SLEEP mode, MCU goes to the ACTIVE mode. Then it saves all necessary information to the EEPROM, close the valve and shutdown all operations.

Another important feature of the gas meter is that it can run with negative credit facility which gives the customer a grace. In this case the meter can run even in the negative balance up to a negative balance threshold set by the utility company. In case of credit run out after office hour or any time when customer can't buy the credit this feature becomes very useful.

2.3 Software Design

The software part of the prepaid system is divided into two parts – central server and vending station. The central server runs an application that communicates with the vending stations and the central database. For redundancy a backup database is also included which automatically syncs with the main database. In case of main database failure, the backup database becomes active without any interruption of normal day to day operation. Any user of the vending station or any system settings or any customer information can be created, deleted or edited from here. The central server is a windows server and the central and the backup databases used are MySQL on linux machines.

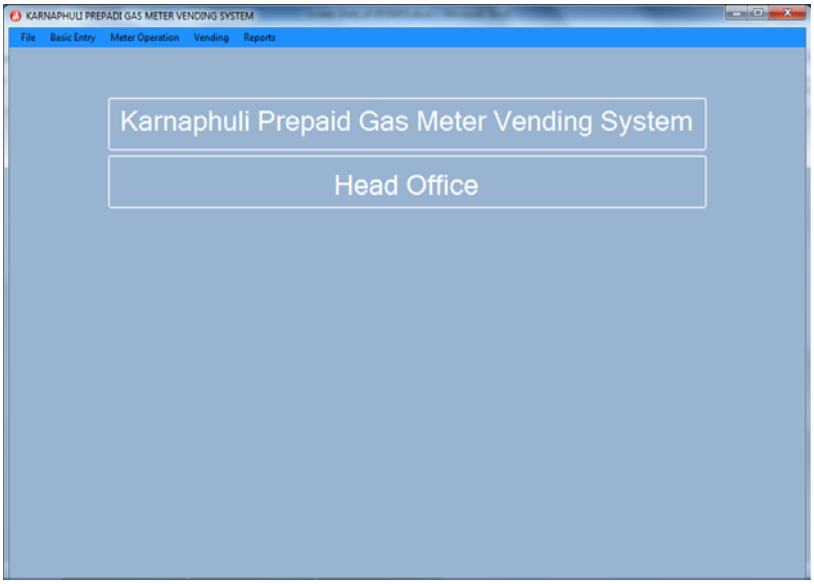

Figure 5: Screenshot of the main screen of vending software

Figure 6 shows the vending window of vending software.

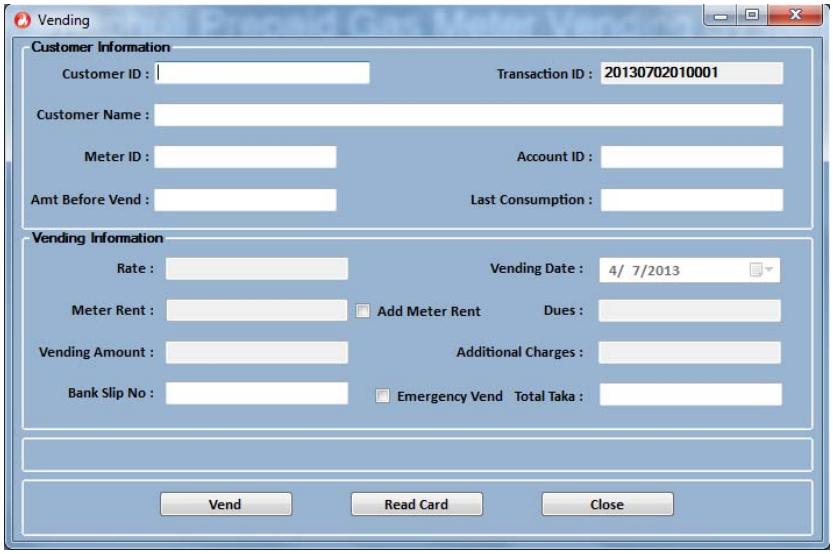

Figure 6: Vending window of vending software

3. Prototype

We have implemented the prepaid contactless gas meter system in our laboratory. We have chosen a gas meter among many others which is suitable in our environment and pressure condition of the utility companies. We attached out designed circuit board with the base meter. We have tested the meter with gas flow and checked all operations of it. The software part was implemented with a central server with backup facility and multiple vending stations. We have simulated all necessary operations which include utility company and customers. The process starts with defining a new customer in server and assigning him a new meter and a unique contactless card. Then some credit is added to the card by vending station. After that the card was used to recharge the balance of the meter. Then the card was checked with the vending station again to extract the data uploaded from the gas meter. We have simulated all operations regarding the design successfully. Figure 7 shows a prototype gas meter based on our design

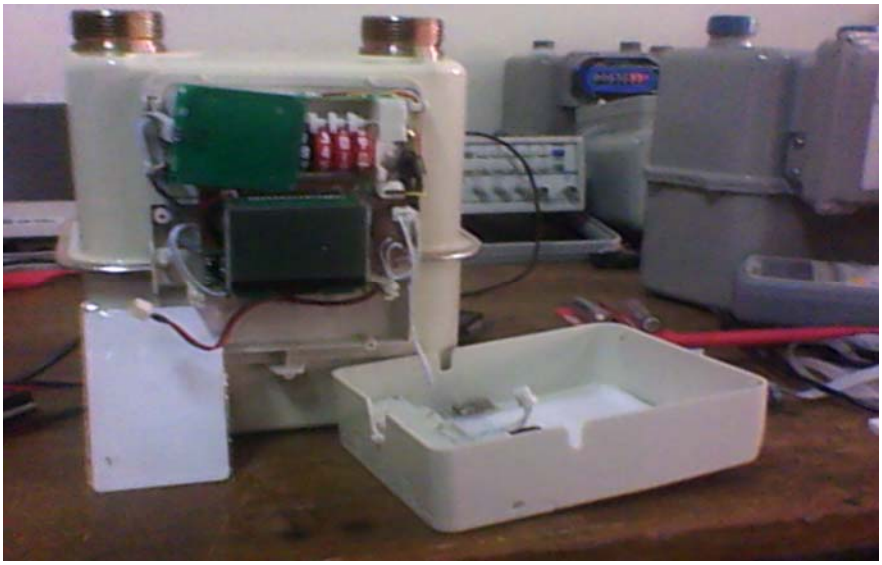

Figure 7: Prototype of the contactless smart card based prepaid gas meter

4. Conclusion and Future Work

In this paper the development of a prototype of contactless smart card based prepaid gas meter are presented. The design algorithm is also mentioned briefly. The prototype has been tested successfully. It also has been demonstrated to different utility companies. It is more secured, user friendly and consumes lower power than the earlier version of prepaid gas meter. In the next step we want to replace the vending station with a portable module which can be placed anywhere. It will increase the flexibility of vending and customers will enjoy more availability of more vending modules. Nowadays NFC standard is becoming popular on cell phones. Many smartphone now includes NFC module that can interact with external NFC modules. We can build smart phone application for the NCF module so that customer can by credit by SMS or from other service and transfer credit to the meter directly from cell phones.

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Biography

Md. Liakot Ali received his B.Sc. degree in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology (BUET) in 1993, M.Sc. in Electrical, Electronic and Systems Engineering from National University of Malaysia in 1998 and Ph.D. in Electronic Engineering from University Putra Malaysia (UPM) in 2001. He served as an R & D Engineer in few reputed national companies of Malaysia and also as Lecturer in University Putra Malaysia. Currently he is working as a Professor in Institute of Information and Communication Technology (IICT), BUET, Bangladesh. His research interests include Embedded System Design, VLSI Design and Testing.

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