A Cognitive Approach for Safe Sodium Phosphate Enema Administration by Implementing Wireless Body Area Network

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ABSTRACT
Recent clinical analysis and medical examinations have reported a numerous adverse effects induced due to improper administration of sodium phosphate colonic preparations given to the patients. Sodium phosphate enema preparation is the treatment for bowel cleansing purposes prior to colonoscopy. It induces serious electrolytic abnormalities in the elderly of which intestinal potassium loss is more prevalent [1]. Inadequate elimination of potassium eventually results in multi-organ failure. This paper encompasses implementation of potassium based biosensors, microcontroller unit for processing and WBAN (Wireless Body Area Network) for precise dosage of sodium phosphate enema preparations. Crown ether layer deposited Ion selective Field Effect Transistor (ISFET) serves the purpose of determining potassium ion concentration in the human blood serum. The results of experimental characterization of the ISFET with ion selective coating as a function of K^+ ion concentration have been demonstrated. This information gathered from MEMFET (Membrane Field effect transistor) is further carried to microcontroller unit for safe level detection of serum potassium level.. Each individual sensor nodes will directly transmit the sensed physiological data to a control unit (CCU) and then to remote stations for diagnostic and therapeutic purposes using UWB and WMTS bands.

Keywords
Ultra Wide Band (UWB), Wireless Body Area Network (WBAN), Ion selective field effect transistors (ISFET), ARM microcontroller, safe enema.

1. INTRODUCTION
With the recent advancements in wireless communication systems and matured semiconductor technology, biosensors have been integrated into micro-analytical systems for improvisation in the diagnostic sectors. Feasibility of miniaturization shows that FET based solid state biosensors are a promising tool and are of great importance to overcome the major challenges in the present healthcare scenario. A systematic review out of a recent literature survey identified the adverse effects of sodium phosphate enemas and associated risk factors. 68% of the patients having adverse effects had associated conditions, the most common being renal failure, gastrointestinal motility disorders and cardio logical diseases [1]. An in-depth study concludes that all side effects were due to electrolytic imbalances. Degradation in potassium levels is much more dominant as compared to the disturbances in other electrolytic entities. Abnormal potassium levels being the epicenter depicts that continuous monitoring of K^+ ion concentration is an indispensable requirement. Potassium ISFET (Ion selective field effect transistors) has been incorporated for the concentration change detection where potassium serves as analyte. Characteristic plot between interfacial membrane solution potential difference and K^+ ion concentration follows a mathematically modeled equation. Microcontroller unit and controlled electronics processes the physiological data sensed by the biosensor and processes it in accordance to the associated algorithm. The transmission of biological data between the sensor node and control unit (CCU) and further remote device interfacing is accomplished by deploying Wireless body area network (WBAN). The purpose of this paper is the joint implementation of potassium selective ISFETs, microcontroller unit and WBAN technology for safe administration of sodium phosphate enema and elimination of adverse effects accompanying it.

2. MOTIVATION & PROBLEM FORMULATION
Monosodium or disodium phosphate enemas are administered for colon cleansing as a preparation for bowel surgical measures and also prior to endoscopic procedures. The cathartic action of sodium phosphate obeys stimulation of rectal motility and osmotic activity which draws plasma water content into the gastrointestinal tract, eventually inducing defecation. However inadequate elimination induces water and electrolytic abnormalities leading to hypokalemia, renal failure (due to Na^+ - K^+ pump impairment) and cardiac arrest [2-6]. The statistics of the patients who have undergone the severity of side effects were referred from the statistical data [1] table VI. Electrolyte balance is crucial for proper kidney function, cardiovascular activity and nerve function. Sodium phosphate induced transient increase in serum phosphorus, sodium, and chloride levels with a concomitant decrease in serum calcium and potassium concentrations [7-9]. Among all ionic entities, potassium ion degradation is fairly prevalent. The excessive depletion of serum potassium causes heartbeat irregularity, raised blood pressure, renal impairment and neurological disorders [1]. An increase in serum phosphorus level was correlated with a decreased creatinine clearance (*R*

= −0.52; *P* = .001) in Fig.1 [10]

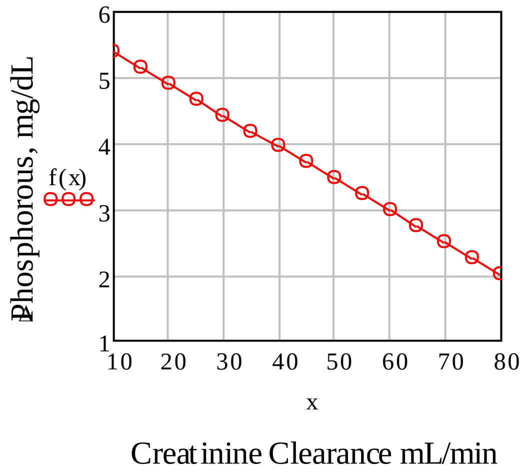

Fig. 1: Phosphorous vs. creatinine clearance characteristics

Inadequate elimination of serum potassium is hereby concluded the thrust area to be worked upon. Considering it ion selective membrane based field effect transistors (MEMFETS or ISFETs) are introduced for the purpose of K^+ ion sensing and continuous concentration monitoring [11-13] .

3. OPERATING PRINCIPLE OF POTASSIUM SELECTIVE ISFET

Currently ISFET serves the purpose of biosensor for determination of serum potassium using dibenzo-18-crown-6(DB18C6) as ionophore. Human blood serum contains potassium in ppm levels i.e., 137 to200 mg/liter and sodium co-exists with a 30 times higher concentration. Such a high concentration tends to interfere the selectivity of potassium but D18C6 proves to have an excellent selectivity towards potassium and is sensitive to the lowest concentration of potassium levels. The crown ether binds the cationic portion of alkali and alkaline earth metal salts (guest) in to the cavity of the crown ring (host).Dibenzo-18-crown-6 used here has a circular cavity of diameter 2.6-3.2 A° which fits the exact size of potassium ion of 2.66 A° and makes it as an excellent choice for sensing material for potassium ions [14]. The binding of a charged ion results in accumulation of carriers caused by change of electric charges on the gate terminal [11-13]. The dependence of the channel conductance on gate voltage makes FETs a suitable bio-receptor because the electric field generating from a cloud of charged ions is analogous to the gate voltage [15]. The figure 2 and 3 demonstrate the complete diagram of ISFET in an electrolytic surrounding using a reference electrode.

The following equation [4] projects the relation between channel current I_{DS} and gate voltage in proportion to the concentration.

$$I_{DS} = \frac{1}{2}\mu\left(\frac{W}{L}\right)C\left[(V_{GS} - V_{th})V_{DS} - \frac{1}{2}V_{DS}^2\right]$$

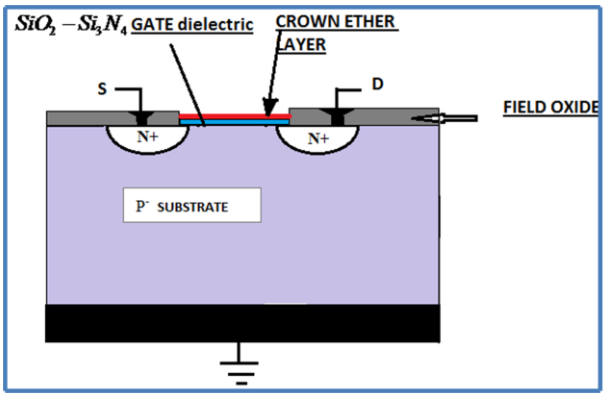

Fig. 2: Crown ether layer deposition on gate area

Where μ represents the electron mobility of device and (W/L) refers to the geometric ratio of gate. C represents the overall capacitance of subsequent layers on sensing area given by the equation

$$C = [\Sigma di/(\varepsilon_i\ \varepsilon_0)]^{-1}$$

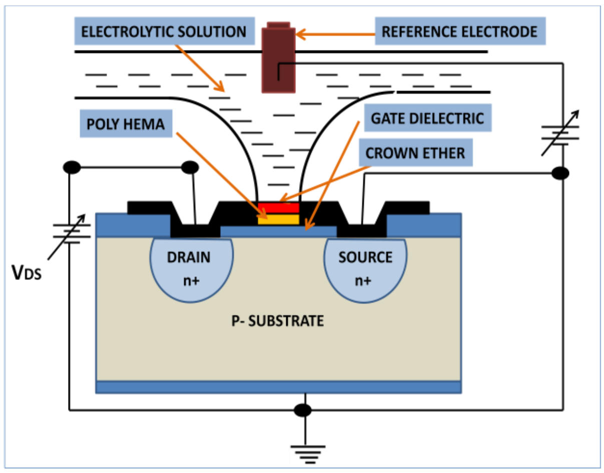

Fig. 3: Structure of ISFET

4. CHARACTERIZATION OF ISFET:

Further the precise measurement of potassium concentration is governed by the device design (channel geometry and structure), ionophoric extraction ability and processing conditions. If the drain current is maintained constant by means of an operational amplifier, which directly controls the applied gate bias potential with a negative feedback loop, the output potential difference varies with change in activity of the sensed ion. The amplified output potential from the signal Conditioning circuit has been plotted with respect to the concentration. The characteristics of voltage vs. concentration

With & without crown ether are shown in Fig4 [14].

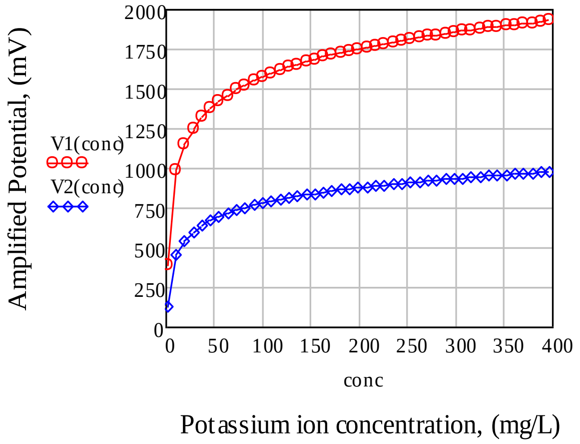

Fig. 4 ISFET Response (a) V1 (slope = 2.3mV /mg/L) with crown ether layer (b) V2 (slope = 1.0mV /mg/L) without crown ether layer

On coating with crown ether layer the characteristics indicates that sensitivity fairly increases due to the extraction capability of membrane. It has been analyzed that average potassium sensitivity without membrane was 1mV/mg/L and that with crown ether was 2.3 mV/mg/L. The ISFET response with respect to the logarithmic concentration resulted into a linear curve. On dividing the slopes by 20 it is estimated that the sensitivity without film is 39.2mV/decade of potassium concentration, which significantly reached up to 56.1 mV/decade after deposition as shown in Figure 5 [14].

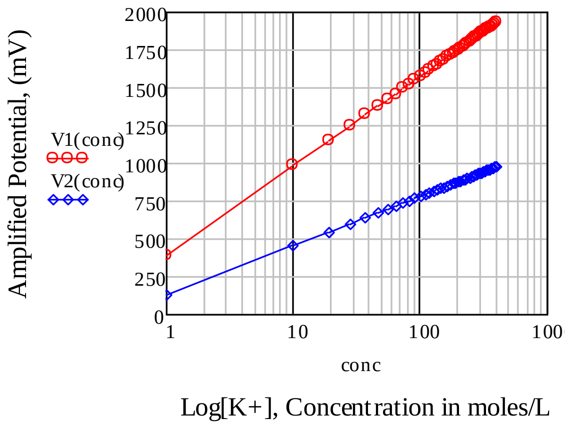

Figure 2 ISFET Logarithmic Response (a)V1 with crown ether layer and (b) V2 without crown ether layer

The ISFET calibration curves are the results of atomic spectroscopy for diluted human blood serum samples. The interfacial membrane solution potential difference varying with concentration depicts that the sensitivity Approaches towards the Ideal Nernstian response of 59mV/decade on applying crown ether film [16].

According to the Eisenmann-Nikolsky equation which is the fundamental principle of all potentiometric transducers, potential changes are logarithmically proportional to the specific ion activity. The Nernst equation is written as

$$E = E^{o} + (56.1).10^{-3} \log[K^{+}]$$

In which, E is the overall electrochemical potential sand E^{o} is the standard electrochemical potential. This is close the theoretical slope of 59mV/decade in a Nernstian response [16]. The mathematical modeling plays a key role in computing the potassium concentration with high specificity.

5. MICRO SENSOR SYSTEM ARCHITECTURE FOR CONCENTRATION ANALYSIS

Initially the I_D / V_G characteristics deduced to the voltage vs. ion activity form by making the drain current constant. The constant channel current controls gate bias voltage by the means of a OPAMP and negative feedback analogous to a trans-impedance amplifier. The achieved output voltage signal is carried for further stages of amplification using a Darlington pair. The analog signal received undergoes through a signal conditioning circuit and gets filtered to eliminate any undesired interferences. Signal transformation from continuous to digital is performed by A/D converter for the processor readable format. The input signal is channelized to the microcontroller through the serial ports (I/P) where in the ROM; data about the safe serum potassium range is indigenously fed. The analysis of the input signal is done by comparing it with the threshold potassium level of 3.5mmol/L in accordance of the algorithm. The code includes the alarm mechanism at the arrival of critical potassium level. Estimation of the potassium concentration is computed by the microcontroller considering the Eisenmann-Nikolsky equation which is an integral part of the code present in the ROM. The irregularity arises in the received signal when it is figured less than the minimum required level, consequently computing the severity of the case. ARM microcontroller suits best for this purpose to analyze the severity and generating the biological information gathered from the biosensor. This physiological data needs to be transmitted from the sensor network implanted in the human body to the practitioner for continuous monitoring of intestinal fluid potassium. Design of Chip assembly for the micro-sensor system (in the human body) is shown in figure 6 below.

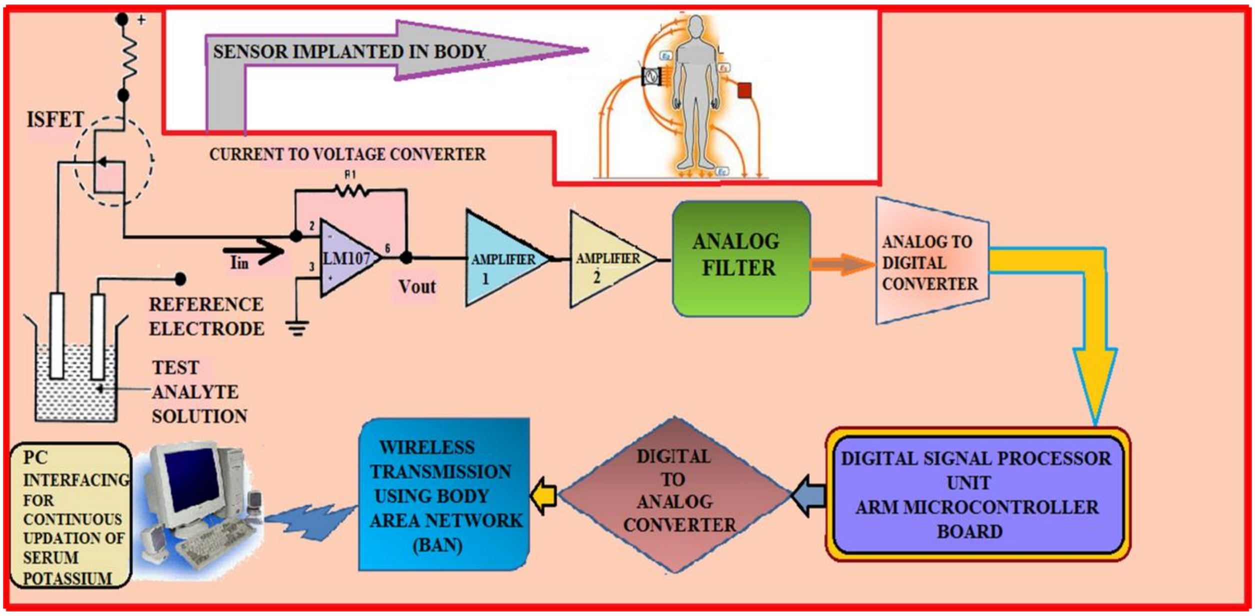

Fig 6. Design of micro-sensor chip assembly

6. CONTINUOUS WAVE SAMPLING BY UWB-BODY AREA NETWORK

The proliferation in sensor networks and miniaturization has empowered the incorporation of Wireless body Area networks for the continuous wave sampling of biomedical signals [17-21]. An integrated WBAN system can synergize the information from the ISFET sensor node, warn the user in the case of emergencies, and provide feedback during normal activity. The requirement for the WBAN technology is justified by the need of faster response and interfacing. For this criterion the sensor device has to be implanted on the intestinal surface to analyze the ion activity in close proximity. This section specifies the network architecture and the wireless standard being used. Each sensor nodes will transmit sensed physiological data to a control unit (CCU) and then to the Personal digital assistant (PDA) or personal devices for wave sampling [22]. Currently, the popular wireless technologies used for medical monitoring are Medical implant Communication service (MICS), Wireless Medical Telemetry Service (WMTS), unlicensed Instrumentation Scientific and medical(ISM) and ultra-wide band (UWB) technology [23]. There are no wireless standards in WBAN for specifically targeting healthcare applications.

Considering the requirement of high data rate transfer and fast response we propose the implementation of UWB technology for this network architecture. Selection of this frequency band is supported by its advantages given below

- For short transmission distance (30 meters) UWB provides accurate measurement ranging in comparison of other wireless standards.
- Average transmission power spectral density is only -45dBm/MHz which is very low while communication to protect human tissue.
- Specific absorption ratio (SAR) is very low on the exposure of this UWB. Hence tissues offer less affinity towards this RF (Radio Frequency) Electromagnetic field leading to a better lossless path model.
- High data rate is achieved and low interference due to other system strengthens its selectivity.
- Low cost design and low power consumption of 30mW facilitates the concept of disposable sensor chips feasible [24].

The figure 7. Below explores the networking architecture from sensor nodes to CCU and further to personal server. Further this section discusses the network architecture of sensor node substructure, CCU and PDA for interfacing. The sensor nodes are designed to undertake three tasks: acquiring signal using front end, digitizing/processing/controlling and finally wireless transmission via a radio transceiver. Before reaching the signal to transceiver it is channelized through the chip assembly circuit discussed in the previous section. The signal is standardized on a carrier wave using a RF modulator. Modulated signal is acquired by the transceiver for further transmission through an antenna. The transceiver operates at a center frequency of 4.1 GHz with a bandwidth of 1.5 GHz [22]. CCU is the intermediate coordinator whose primary function is to collect data from sensor nodes via the wireless UWB band link. It is a relay node consisting of a microcontroller and transceivers to coordinate all activities. This device comprises of dual wireless transceiver to support two directional wireless links. The associated receiver is conventionally a low pass filter for the demodulation of the carrier wave. The signal is modulated again for the secure and effective wireless transmission. FM-UWB is an emerging technology for robustness towards interference and low specific absorption ratio [24].

8. CONCLUSIONS & COMPARATIVE ANALYSIS:

Several guidelines have been developed for treatment of hypertonic sodium phosphate solutions in optimum amount [28]. However an ubiquitous monitoring system is an inevitable requirement since electrolytic activities have to be regularly reported to avoid any abrupt effects on the cardiac and renal action. The overall sophisticated system is an

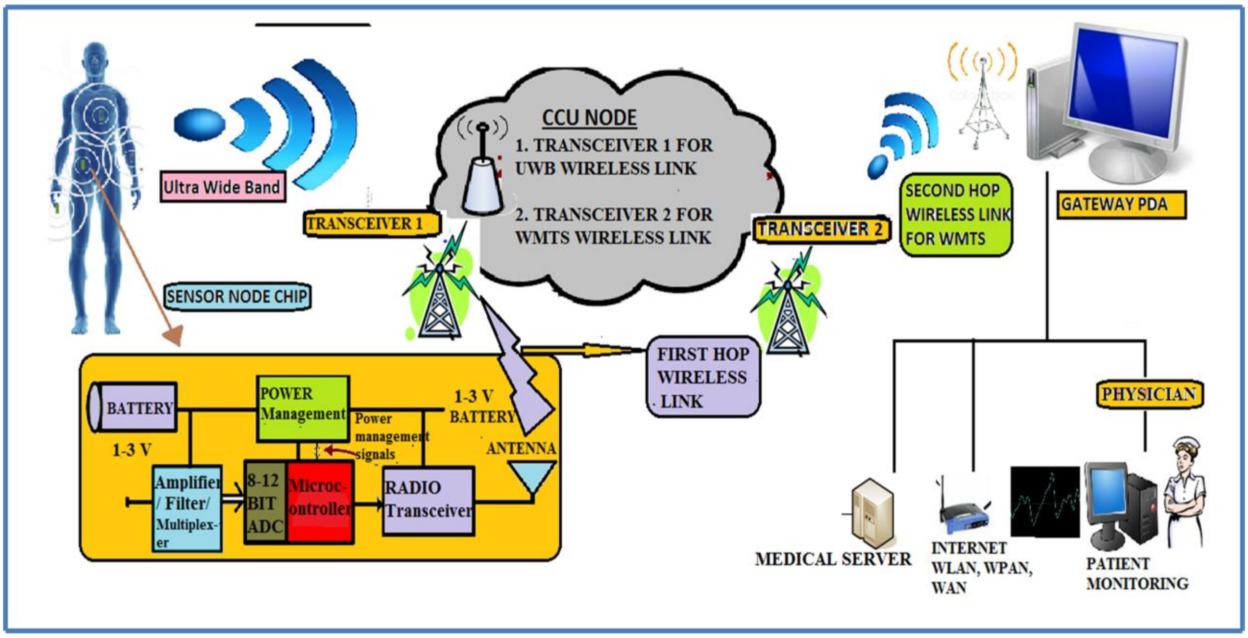

Fig 7. Network infrastructure of UWB-WMTS gateway for continuous monitoring

transmission to the remote PDA or personal device in respect of WMTS band for second hop wireless link[25-27]. WMTS usually operates at 1395-1400 MHz of the frequency band [17]. Acquisition of biological signal on a personal server can further be transferred at the remote stations via Wi-Fi or Bluetooth. The combined approach of UWB and WMTS technology plays a vital role in cost effectiveness and low power consumption for the WBAN gateway design.

7. FUTURE APPLICATION PROSPECTS

Future design of the proposed system should concentrate on a number of sectors including hardware and protocol design. The hardware development focuses on the sensor level where different membrane materials in ISFET are expected to give more efficient sensitivity results. The ionophoric membrane apart from crown ether must possess better affinity for potassium ions. A real time implementation of a low cost micro-sensor chip is required by employing ARM microcontroller and associated circuit design. A dedicated adaptive wireless protocol should be designed for WBANs for

interdisciplinary approach to prevent the adverse effects induced due to inadequate enema administration. The paper explores the correlation between the post-effects and excessive potassium depletion. The role of crown ether deposited ISFET pertaining to regular cognition of potassium ions has been demonstrated. The digitization, processing and alarm mechanism to define critical level of the serum potassium has been explained by its chip assembly design. An adaptive architecture of WBAN employing UWB and WMTS has been shown to accommodate critical and non critical data with low latency and low information loss probability.

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