Computer Communications 148 (2019) 176–184

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Tooth implant prosthesis using ultra low power and low cost crystalline carbon bio-tooth sensor with hybridized data acquisition algorithm

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ARTICLE INFO

Keywords:
Tooth bio-sensor
Data logger
Tiny ultra-low power and low cost tooth sensor
Bio-chemical nature
Prosthesis

ABSTRACT

This paper proposes a tiny ultralow-power and low-cost tooth sensor with hybridized data processing algorithm for monitoring implant tooth implant prosthesis performance. In general micro displacement or any fatal damages in prosthesis tooth implant leads to various metabolic alterations in the body. This tiny ultra-low power and low-cost crystalline carbon bio-tooth sensor has been placed on tooth platform to monitor mouth and tooth bio-chemical nature which leads to check the prosthesis volume and its structural modification instantaneously in turn helps doctors to observe the metabolic alterations in the body. This wireless system has data loggers with hardware and software power-saving modes for ultra-lower application for reducing sensor idle state condition has been monitored using a hybridized acquisition algorithm. Clinical Trials of the lab-scale experimental analysis equipped with data logger device are analyzed on 15 patients on various factors such as noise factor, power consumption, accuracy, efficiency, stability and sensitivity of the sensor output characteristic has been recorded.

1. Introduction

In the Present scenario, high tech wearable bio-tooth sensor is designed to monitor the health and various dietary habits which gives complete information about the sugar, salt, tooth structure and various bio-chemical component present in the mouth [1]. This wireless sensor helps nutritionist to monitor the tooth and diet activity of the person on every time with fewer effects [2]. The Food which passed through the mouth touches the tooth may alter or damage the structure of the tooth as well it alters the bio-chemical component of the mouth during the secretion of saliva [3,4]. This bio-tooth sensor proposed in this research acts as a bio-marker which helps to monitor the overall health as well as tooth structure through measuring chemical composition and structural analysis [5]. Though various wearable sensors are used in the market to monitor overall health effects and tooth structure, these wearable sensors are not optimized in various factors such as noise factor, power consumption, accuracy, efficiency, stability, sensitivity and specificity [6,7]. In this research, we are much focused on optimizing the required parameters through proper calibration of sensors and sensitive elements used in the logical architecture. The sensitive elements used in the design has the ability to detect pH, glucose and structure of the tooth [8], furthermore, the data has been transmitted either wireless through radio frequencies by altering the suitable material combination which helps to detect the oral cavity on the surface of the teeth. In general the oral cavity could be analyzed based on saliva sampling and various biochemical components secreted in the mouth. At present the existing device refinement is required which is considered as one the significant area of research in this article by selecting proper sensor and effective algorithm for data processing. In the tradition wearable's various data processing algorithms are used such as silicon-based stress analyzer on tooth (SSAT), three-dimensional force sensor (TDFS) Tooth inspired Tactile sensor (TITS) and so on [9,10]. All the sensor available in the markets lags in several parameters which has been addressed in this research and the contribution of the work is as follows,

- Battery free operated-Ultra-low power device
- Wireless readout with remote sensing competence
- Improved hybridized data processing algorithm for data loggers or data acquisition system
- Enhanced digital logic architecture by optimizing SRAM

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https://doi.org/10.1016/j.comcom.2019.09.020
Received 30 June 2019; Received in revised form 15 September 2019; Accepted 27 September 2019
Available online 30 September 2019

- Novel Crystalline carbon-based design development of bio-tooth sensor

The rest of the paper is as follows where Section 2 discussed various literature survey on tooth-bio sensor and other wearable technologies and its importance, Section 3 discussed the ultra-low-power and low-cost tooth sensor with hybridized data acquisition algorithm, Section 4 Validate the experimental results and discussion on various parameters, Section 5 concludes the research with future extension.

2. Literature survey

As of late Tufts University School of Engineering built up a sensor unit which screens constantly, what occurs in and around our bodies which are can be precious with regards to medicinal services or clinical examinations, yet not all that simple to do. In the current overview, on wearable units for observing dietary of humans for example, requiring the utilization of a mouth monitor, massive wiring, or requiring regular substitution as the sensors quickly corrupted due to complexity. This made analysts looked for a progressively adaptable innovation and built up a sensor with an insignificant 2 mm × 2 mm impression bio responsive marker (BRM) [11] that can adaptable, adjust and attach to the unpredictable surface of a tooth. As per the recent survey, Internet of things (IoT) sensor collects data about every day dietary nourishment which is inspected by applying various algorithms such as artificial intelligent systems (AIS) [12], k-means algorithm (k-means) [13], neural system (NS), bolster vector machine (BVM), Bayesian classifiers (BC) [14,15] and so on for recognizing the nature of tooth and mouth bio components.

The above-examined techniques are hard to foresee biochemical components and structure of the tooth due to complexity in analyzing data and less robustness. The above issues can be overcome using wearable sensor devices because this wearable device has integrated tooth and bio-component monitoring unit which helps doctors to detect and monitor the whole tooth and mouth in an easy way [16]. The device gathers the different nourishment admission levels, for example, nibbles, gulping, biting and so on [17]. The data is transmitted using General packet radio service and Global system for mobile communication for analyzing the nature of tooth and its structure along with bio-component [18,19]. Even though, this sensor design and data processing algorithms are hard to design and develop because it is hard to find the intake of food separately with less power, noise and more accuracy [20,21]. For this reason, this ultra-low power and low-cost crystalline carbon bio-tooth sensor has been placed on tooth platform to monitor mouth and tooth bio-chemical nature which leads to check the prosthesis volume and its structural modification instantaneously in turn helps doctors to observe the metabolic alterations in the body as well as it monitors biochemical component, tooth structure, sugar, salt and cholesterol level and results are examined based on experimental analysis as discussed below.

3. Ultra low power and low cost tooth sensor with hybridized data acquisitionalgorithm

The elementary operation and the significant functionality of the crystalline carbon-based Bio-tooth sensor design along with data acquisition system for sensor data processing with the monitoring center has been schematically illustrated in Fig. 1. This architecture consists of a crystalline carbon-based sensing unit which is named scientifically named as graphite that has been designed and developed with wireless readout. This ultra-low-power bio-tooth sensor is integrated on tooth enamel which has been shown in Fig. 1 with large surface carbon property ensures extremely high epoxy resin to the tooth surface. The usage of crystalline carbon with high graphite property increases the electronics sensing property of this bio-sensor used which is specifically used in various bio recognition operation on wearable sensor unit in diverse medical sectors. This sensor has major advantages which are listed as follows:

- Battery-free operated-Ultra-low power device
- Wireless readout with remote sensing competence

As shown in Fig. 1. This ultra-low power bio-tooth sensor is mounted on the surface of the tooth and the resulting stress has been measured using sensor chip data processing unit which can be readout wireless and the measured data has been externally processed using Field Programmable Gate Array (FPGA) at monitoring center for low power medical data processing application. Here measure stress data has been analyzed using hybridized data processing algorithm where the data is processed at Static Random Access Memory (SRAM). This hybridized algorithm analyzes the data which are retrieved from the tooth bio-sensor which measures stress function data of the tooth and fitting coefficients of the sensor. This sensor monitors mouth and tooth bio-chemical nature which leads to check the prosthesis volume and its structural modification instantaneously in turn helps doctors to observe the metabolic alterations in the body.

3.1. Sensor design

This silicon stress sensor consists of four partitions such as Bulk, Drain, Source and Gate which has dual polarity Piezo-Resistor Sensor (PRS) 1 to 4 as shown in Fig. 2 and the coefficients of the sensor are named as fitting coefficients which has PRS calibration. This plane has 10 length and Width as well as 3 sized of p-type and n-type PR pair which are placed 450-degree doping concentration. This fitting coefficients and the sensor factor based on change in PR resistance configuration has been analyzed for this bio-tooth sensor chip based on out of plane and in-plane stress factor. As the out-plane factor is considered as negligible as in-plane factor, it has been neglected for mathematical formulation to calculate the stress factor as Equated and shown in Eq. (1).

$$\frac{R\theta_1}{R\theta_1} = \frac{\delta_S^p}{2}\left(\alpha_{11}+\alpha_{22}\right) + \frac{\delta_{44}^p}{2}\left(\alpha_{11}-\alpha_{22}\right) + C_p(T) \tag{1}$$

$$\frac{R\theta_2}{R\theta_2} = \frac{\delta_S^p}{2}\left(\alpha_{11}+\alpha_{22}\right) - \frac{\delta_{44}^p}{2}\left(\alpha_{11}-\alpha_{22}\right) + C_p(T) \tag{2}$$

As shown in Eqs. (1) and (2) where $\frac{R\theta_1}{R\theta_1}, \frac{R\theta_2}{R\theta_2}$ is the initial resistance where changes of resistance has been denoted as θ_1, θ_2. The normal stress factor of the bio-tooth sensor is represented as $\alpha_{11} + \alpha_{22}$ has been placed along the out-plane direction with the temperature fitting coefficient factor as denoted as $C_p(T)$.

$$\frac{R\theta_3}{R\theta_3} = \frac{\delta_S^n}{2}\left(\alpha_{11}+\alpha_{22}\right) + \delta_D^n\alpha_{12} + C_n(T) \tag{3}$$

$$\frac{R\theta_4}{R\theta_4} = \frac{\delta_S^n}{2}\left(\alpha_{11}+\alpha_{22}\right) + \delta_D^n\alpha_{12}\frac{\delta_{44}^p}{2} + C_n(T) \tag{4}$$

As shown in Eqs. (3) and (4) where $\frac{R\theta_3}{R\theta_3}, \frac{R\theta_4}{R\theta_4}$ is the initial resistance where changes of resistance has been denoted as θ_3, θ_4. The normal stress factor of the Bio-tooth sensor is represented as $\delta_D^n\alpha_{12}$ has been placed along the in-plane direction with the temperature fitting coefficient factor as denoted as $C_p(T)$.

In General the n and p used in the δ_D^n, δ_S^p denoted the concentration of p-type and n-type material respectively, where as {D,S} Denotes PR fitting coefficients Equated in Eqs. (5) and (6) as represented as follows,

$$\{\delta_S^p, \delta_D^n\} = \alpha_{11} + \alpha_{22} \tag{5}$$

$$\{\delta_S^n, \delta_S^p\} = \alpha_{11} - \alpha_{22} \tag{6}$$

From Eqs. (5) and (6) the Following mathematical derivation has been computed to derive the respective normal stress factor of the bio-tooth sensor as shown in Eqs. (7) and (8).

$$\alpha_{11} = \frac{1}{2\alpha_S^p}\left\{\frac{R\theta_1}{R_1} + \frac{R\theta_2}{R_2}\right\} + \frac{1}{2\alpha_{44}^p}\left\{\frac{R\theta_1}{R_1} - \frac{R\theta_2}{R_2}\right\} + C_p(T) \tag{7}$$

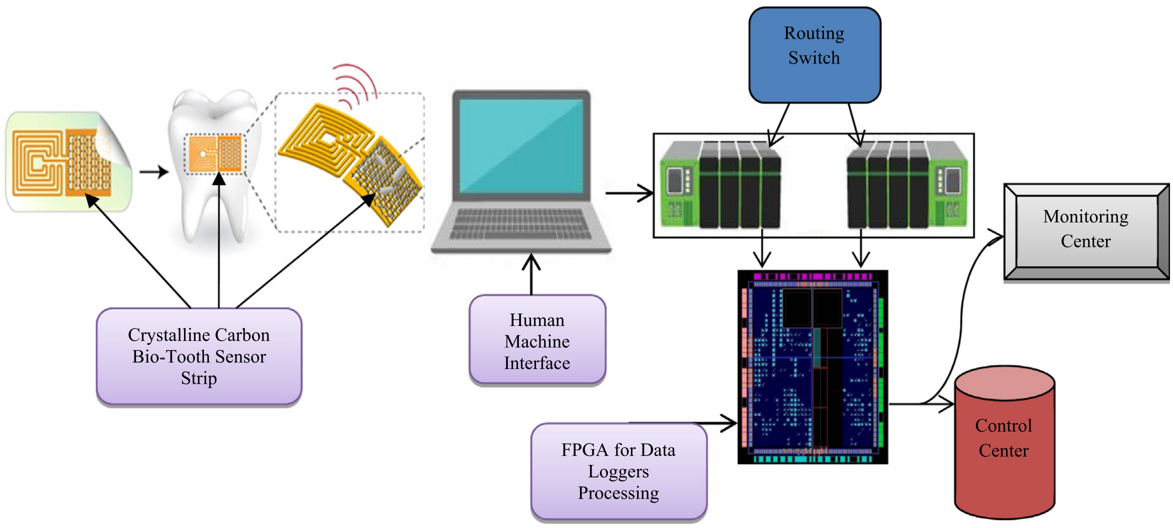

Fig. 1. Bio-transfer of crystalline carbon based bio-sensor for tooth monitoring with data acquisition system.

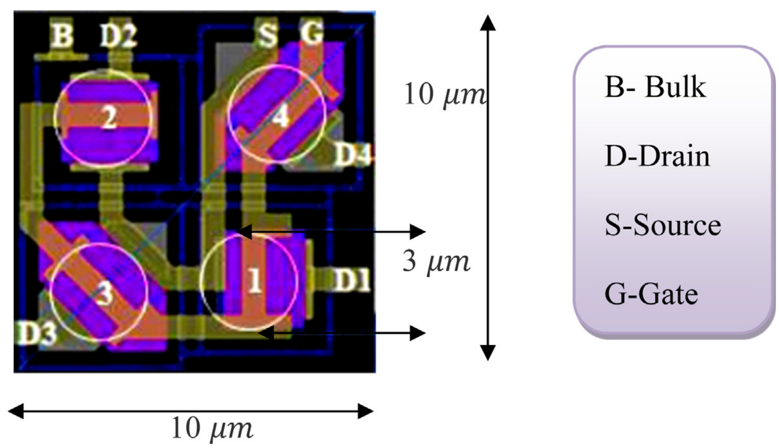

Fig. 2. Silicon stress sensor integrated on crystalline carbon Bio tooth sensor.

$$\alpha_{22} = \frac{1}{2\alpha_S^p}\left\{\frac{R\theta_1}{R_1} + \frac{R\theta_2}{R_2}\right\} - \frac{1}{2\alpha_{44}^p}\left\{\frac{R\theta_1}{R_1} - \frac{R\theta_2}{R_2}\right\} + C_p(T) \tag{8}$$

From the Eqs. (7) and (8) α_{22} has been derived by solving $\alpha_{11} - \alpha_{22}$ and the corresponding fitting coefficient of the bio-tooth sensor has been equated in Eqs. (9)–(11) as follows,

$$\alpha_{11} - \alpha_{22} = \frac{1}{2\alpha_{44}^p}\left\{\frac{R\theta_1}{R_1} - \frac{R\theta_2}{R_2}\right\} \tag{9}$$

$$\alpha_{11} - \alpha_{22} = \frac{1}{\alpha_{44}^p}\left\{\frac{R\theta_1}{R_1} - \frac{R\theta_2}{R_2}\right\} \tag{10}$$

$$\alpha_{12} = \frac{1}{\alpha_D^n}\left\{\frac{R\theta_1}{R_1} - \frac{R\theta_2}{R_2}\right\} \tag{11}$$

From the derived Equations, both normal stress fitting coefficient and the corresponding shear fitting coefficient are independent to temperature which shows the Eqs. (10) and (11) does not require temperature factor. Once the fitting coefficient has been calculated the data has been readout wireless to analyze the tooth as well as mouth bio-chemical nature through stress/shear measurement, this readout circuit has been designed and developed with the capability to read out the data based on automatic program control SRAM processing unit where the hybridized data processing algorithm has been integrated. This hybridized data acquisition system has a bio-tooth sensor which has crystalline carbon with Silicon on insular (SOI) is fabricated with a thickness of 100 polished using nano-particles for mechanical strength and high resistance. Here P-type and N-type metal oxide semiconductor(MOS) has been used in the sensor for low power application and logical circuit consists of multiplexer which acts as a data switch for passing the data at output based on the selection line which has been programmed in the sensor. At last the processed data has been stored in the buffer unit for wireless readout as shown in Fig. 3.

Table 1
Hybridized Routing tabulation for data processing at tooth bio-sensor.

Hybridized Routing for data processing at tooth bio-sensor		
Logic State (LS)	Snooze State (SS)	State of function
Logic-‘1’	Undetermined	Dynamic
Logic-‘0’	Logic-‘0’	Sleep

3.2. Hybridized data acquisition system with logical sensor architecture

As shown in Fig. 3 the logical circuit of the 4T-SRAM named as 4-Transistor with sensor data processing unit has two states named as Sleep and Drowsy state where Drowsy = Logic ‘1’ and sleep = “OFF” makes the sensor unit at snooze logic which predicts data more accurately compare to traditional sensor system which are available in for data read-out and the corresponding switching function has been listed in Table 1.

As shown in Table 1, the distinct function has been noted based on the various cases as listed below, In general the sensitive(S) data is

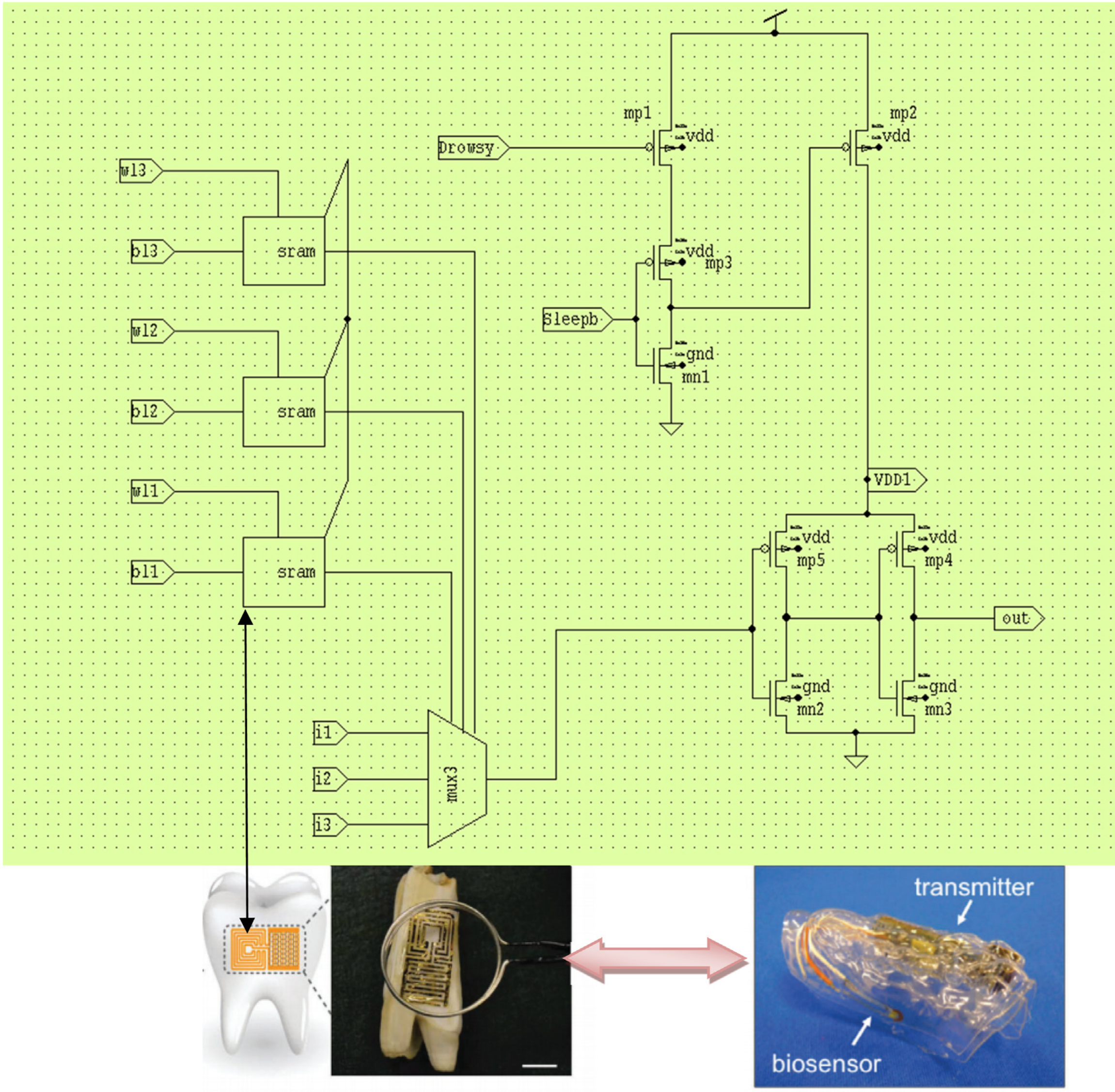

Fig. 3. Crystalline carbon Bio-tooth sensor data processing SRAM unit logical architecture with hybridized acquisition algorithm.

shown in Eqs. (12) and (13) based on the sensor readout as given below where C_p and C_n denotes the concentration of p-type and n-type respectively which is represented as $S\,(p-type, n-type)$ $\ in\ respect\ ton\ and\ p\ type.$

$$S\,(p-type, n-type) = \frac{\iint_0^N C_{p,n} * (p-type, n-type)}{\iint_0^N (C_{p,n}\,(p-type, n-type)\, C_N\,(p-type, n-type))^{\frac{1}{2}}} \tag{12}$$

$$S\,(p-type, n-type) = \frac{\iint_0^N C_{p,n} * (p-type, n-type)}{\iint_0^N (C_{p,n}\,(p-type, n-type)\, C_N\,(p-type, n-type))^{2}} \tag{13}$$

From Eqs. (12) and (13), the change of data with various cases are listed as follows,

Case: 1: $SS = Logic``0", Transistor\ \ Logic = MP1, MP3, MP5 = Logic``1"$

Proof. Conditional check of sleep_state as logic“1” makes the transistor $MP1, MP3, MP5 = Logic``1"$ where the power is obtained through MP4.

Case: 2: $SS = Logic``1", Transistor\ Logic = MN1, MP4 = Logic``1"$

Proof. Conditional check of sleep_state as logic“1” makes the transistor $MN1, MP4 = ``ON"$ where the power is obtained through MP4.

Case: 3: SS and $Sleep_{State} = Logic``0", Transistor\ Logic = MN2, MP1, MP3 = Logic``1"$

Proof. In this check the sleep_stateand Snooze state as logic“0” makes the transistor $MN2, MP1, MP3 = ``ON"$ where the power is obtained through supply voltage will be stopped and $MN2 = Logic``1"$

Case 4: $Drowsy(D) = Logic``1"$, and $Sleep_{State} = Logic``0", Transistor\ Logic = MN2, MP2, MP3 = Logic``0"$

Proof. In this check the DandSleep_state as logic“0” makes the transistor $MN2, MP2, MP3 == ``OFF"$, here the circuit has been operated in drowsy mode. The lower swing will be reduced which is considered as one of the foremost problem in the existing data processing unit of the sensor which has been overcome by the 4T-Hybridized Routing for data processing unit where the algorithmic structure has been discussed in Algorithm 1.

```
Set Logic S, D, SL, P and N transistor;

Ensure: Never Snooze State

//* The S (Snooze), D (Dynamic), SL (Sleep)//*

        Start:
        Begin
        Case1&2: If (SS=Logic '0')
                MP1|MP3|MP5 =Logic '1';
                Power= MP4
                Else
                MN1|MP4 =Logic '1';
        Case 3 : If (SS|Sleep_State=Logic '0')
                MN2|MP1|MP3 =Logic '1';
                Power= MN2
                // *Supply Voltage Passage will be Stopped//**
                Else
                MN2|MP1|MP3 =Logic '0';
                Else
                MN2|MP4 =Logic '1';
        Case 4 : If (D|Sleep_State=Logic '0')
                MP3, MP2, MN2=OFF
                Sets(S= Logic '1' &&SL=Logic '1')
                //*"Never Snooze State"//
                Else
                Switch (Set-1);
                MP3, MP2, MN2= "ON"
                End if
                End Begin
```
Algorithm1: Hybridized Data processing flow of 4T-SRAM on Crystalline Carbon Bio-Tooth Sensor

Whenever snooze logic is at sleep state which makes the transistor "OFF" during sensor data analysis, At this state control, current leakage is less which places circuit at low switching state which helps minimize the unwanted switching of transistors through optimizing vdd = Logic"1" and MP1 = Logic"1" makes the sensor more suitable for ultra-lower power operation in medical wearable sensor unit specialty for bio-tooth sensor which has been designed in the research and the corresponding formulation is explained in the algorithm 2

```
Set Logic S, D, SL, P and N transistor;

Ensure: Never Snooze State

Ensure: Less noise and Less power

\* The S (Snooze), D (Dynamic), SL (Sleep) //*

        Start:
        Begin
        Conditional Check_1: If (MP1="ON")
                MP2|MP3 ="ON";
                Otherwise
                MN1|MP3 ="OFF";
        Conditonal_Check_2 : If (Vdd="ON")
                MP2|MP3 ="ON";
                MP4|MP5 ='Sleep Mode';( Lower Switching Activity)
                Else
                MP2|MP3 =Logic '0';
                MP4|MP5 ='Sleep Mode';(Lower Switching Activity)
                \* all transistors Saturation mode of operation prevents noise*\
        End if
        End Begin
```
Algorithm.2. Unwanted Switching Flow Reduction flow for bio-tooth sensor

The characteristics of Hybridized data processing unit (HDPU) are analyzed using FPGA. HDPU consist of cascaded current and switching pair. This current sources are depends on the inputs MN1 and MN2 transistor. These transistors are used to reduce the parasitic effect and the high input impedance effect has been reduced using MP2 and MP3 transistors. Furthermore in order to smoothen the output current, the transistors are operated in saturation region which helps to minimize the switching activity and makes the transistor operated in sleep state. This conditional check helps to reduce the power as well as noise factor of the bio-tooth sensor unit during data processing operation. This HDPU has experimentally validated based on the noise factor with high robust and stability, power consumption and improves Accuracy, efficiency, stability and sensitivity of the sensor output as discussed below.

Table 2
Efficiency of the Bio-tooth sensor unit with hybridized algorithm.

Patients datasets	SSAT	TDFS	TITS	AIS	NS	BC	CCBS-HD
1	80.11	81.22	88.99	89.88	89.9	90.11	91.22
2	81.22	79.33	81.22	85.44	93.44	95.11	98.77
3	85.44	85.44	85.44	86.44	90.22	95.44	98.77
4	83.44	75.33	83.44	85.44	89.22	93.22	98.77
5	84.55	84.55	89.66	83.22	93.22	89.66	98.55
6	86.55	86.55	89.66	90.22	91.22	90.33	98.77
7	85.44	85.44	83.22	89.55	92.33	91.22	98.88
8	83.22	83.22	81.22	88.44	88.55	92.33	98.89
9	89.44	89.44	90.11	89.44	94.55	95.44	98.89
10	90.11	90.11	91.22	91.22	95.44	91.11	98.89

4. Experimental validation and discussion

In this research the primary evaluation has recorded at lab scale for 15 patients where the bio-tooth sensor has been placed on their respective teeth and furthermore monitoring center which reports data as per the data loggers output which has been processed using FPGA. The set of 15 patients are taken for analysis at lab scale is shown in the Fig. 4. Here patients with normal health teeth and gums are shown in Fig. 4(a) has taken from *lab archives biomed central edition database* and the reference is mentioned in the Fig. 4., where the unhealthy teeth and cavities are listed in Fig. 4(b), Further more unhealthy cavities and sore gums are listed in Fig. 4(c). Clinical Trials of the lab scale experimental analysis [21] equipped with data logger device are analyzed on various factors such as noise factor, power consumption, accuracy, efficiency, stability and sensitivity of the sensor output characteristic has been recorded.

This silicon stress sensor consists of four partitions such as Bulk, Drain, Source and Gate which has dual polarity Piezo-Resistor Sensor (PRS) as discussed earlier and This sensor plane has 10 μm length and Width as well as 3 μm sized of p-type and n-type PR pair which are placed 45° degree doping concentration is shown in the Fig. 5.

HDPU circuits consist of two cascade transistors MN1 and MN2. In this design, the MN2 is used to isolate the parasitic capacitance of the current source transistor MN1. These two MP2 and MP3 transistors are used for achieving the high output impedance shows more efficiency than SSAT, TDFS, TITS AIS, NS and BC. The Tabular representation of outcomes is shown in Table 2

This crystalline carbon with Silicon on insular (SOI) is fabricated with the thickness of 100 μm polished using nano-particles for mechanical strength and high resistance is shown in Fig. 5, the sensitivity of the bio-tooth sensor is the ratio of resistance with respect to input force as equated in Eq. (14) as Follows,

$$S = \frac{R\theta}{F} \tag{14}$$

where, "S" is the sensitivity and $\frac{R\theta}{F}$ change in resistance with respect to Force. Further the Sensitivity has been analyzed based on the stress factor which is shown in Eq. (15),

$$Stress = \frac{3F(l - D)}{wT} \tag{15}$$

where, "l" is the length and "D" is the distance where it shows the difference between two supporting sensors mounted on the blade and "w" is the width and "T" is the thickness of the sensor. The sensitivity data is analyzed based on $\sum True\ positive\ Datasets$ as well as $\sum True\ positive\ Datasets + \sum False\ Negative\ Datasets$ as shown in Eq. (16) and the proposed Crystalline carbon bio-tooth sensor with Hybridized data processing (CCBS-HDP) algorithm is compared with

Fig. 4. Patients teeth taken for analysis [22–25].

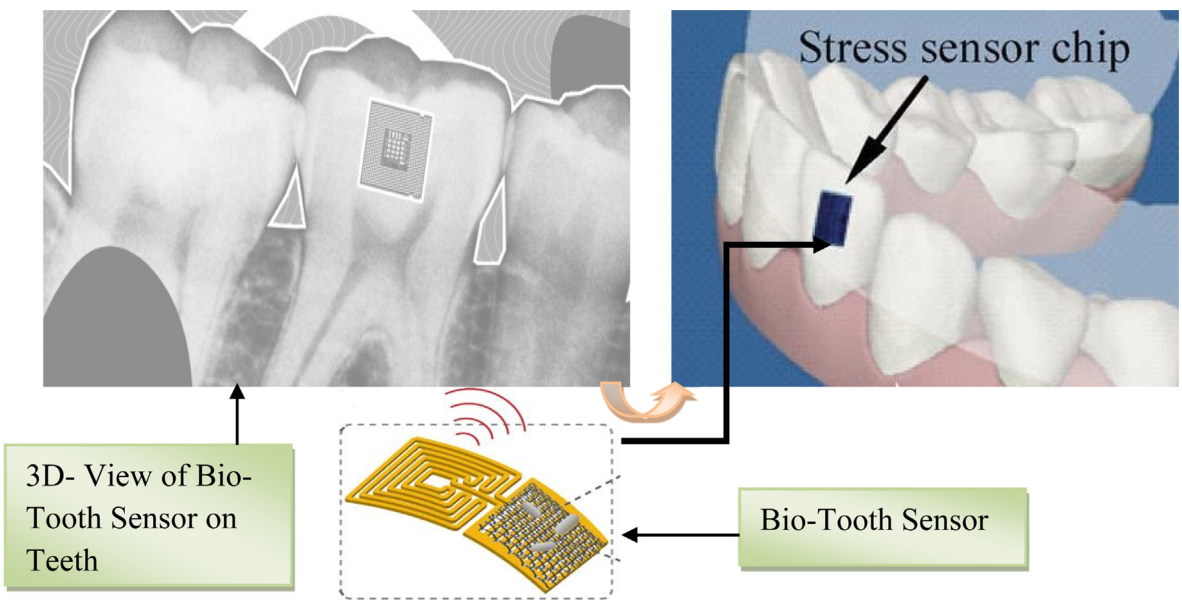

Fig. 5. Crystalline carbon bio-tooth sensor mounted on teeth.

SSAT, TDFS, TITS AIS, NS and BC. The Graphical representation of outcomes is shown in Fig. 6

$$Sensitivity = \frac{\sum True\ positive\ Datasets}{\sum True\ positive\ Datasets + \sum False\ Negative\ Datasets} \tag{16}$$

The Power consumption of the sensor is validated based on Sleep state = Logic '0' and snooze = Logic '1' and after that circuit ends up sleepy. At this state control, leakage is less which places circuit at low switching state which reduces unwanted switching activity of the transistor through optimizing vdd = Logic"1" and MP1 = Logic"1" makes the sensor more suitable for ultra lower power operation in medical wearable sensor unit specialty for bio-tooth sensor and the corresponding power equation is shown in the Eq. (17)

$$\text{Power} = P_{\text{switching}} + P_{\text{shortcircuit}} + P_{\text{leakage}} \tag{17}$$

• **Switching Activity Factor:** α

$$P_{\text{switching}} = \alpha.f.Ceff.Vdd \tag{18}$$

$$P_{\text{shortcircuit}} = vdd * Frequency * I\,(sc) \tag{19}$$

$$P_{\text{leakage}} = vdd * v\,(TH)\,, width/length \tag{20}$$

As shown in the Eqs. (17) and (18) Switching Activity Factor is named as: α with effective capacitance $Ceff$ and the supply voltage Vdd. The short circuit and leakage power is estimated. As shown in Eqs. (19) and (20), Whereas Leaked depends on channel length. The proposed CCBS-HDP approach is compared with SSAT, TDFS, TITS AIS, NS and BC. The Graphical representation of outcomes is shown in Fig. 7

In general Accuracy of the bio-tooth sensor is defined as the $\sum(True\ positive + True\ negative)datasets$ values as predicted by the logical circuit in accordance with the summation of $\sum(True\ positive + False\ Negative + True\ negative + False\ positive)Datasets$ shown in Eq. (21). In this research the logical circuit of the 4T-SRAM named as 4-Transistor with sensor data processing unit has two states named as Sleep and Drowsy state where Drowsy = "ON" and sleep = "OFF" never makes the sensor unit to snooze logic which predicts data more accurately compare to traditional sensor system which are available in for data read-out such as SSAT, TDFS, TITS AIS, NS and BC as shown in Fig. 8

$$Accuracy = \frac{\sum(True\ positive + True\ negative)datasets}{\sum(True\ positive + False\ Negative + True\ negative + False\ positive)Datasets} \tag{21}$$

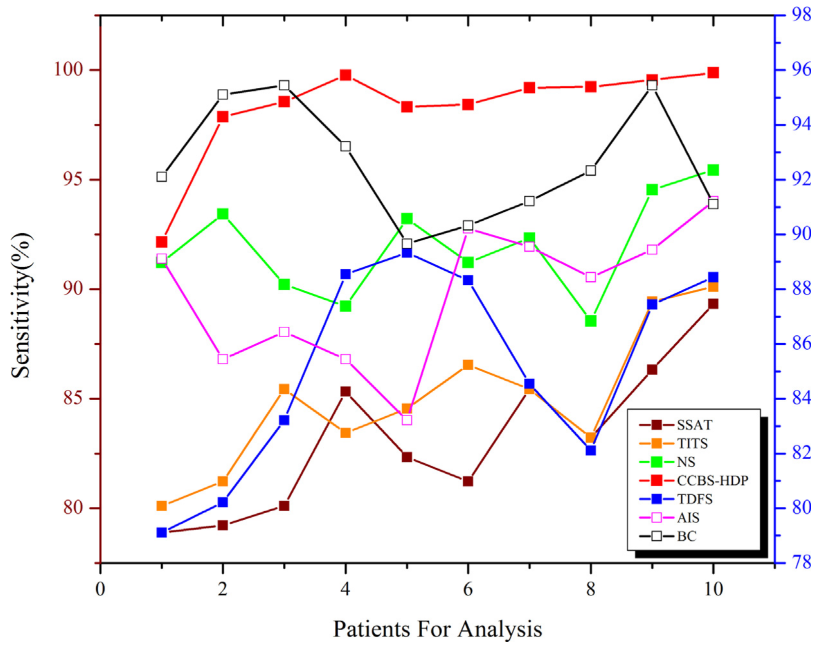

Fig. 6. Sensitivity analysis for the bio-tooth sensor.

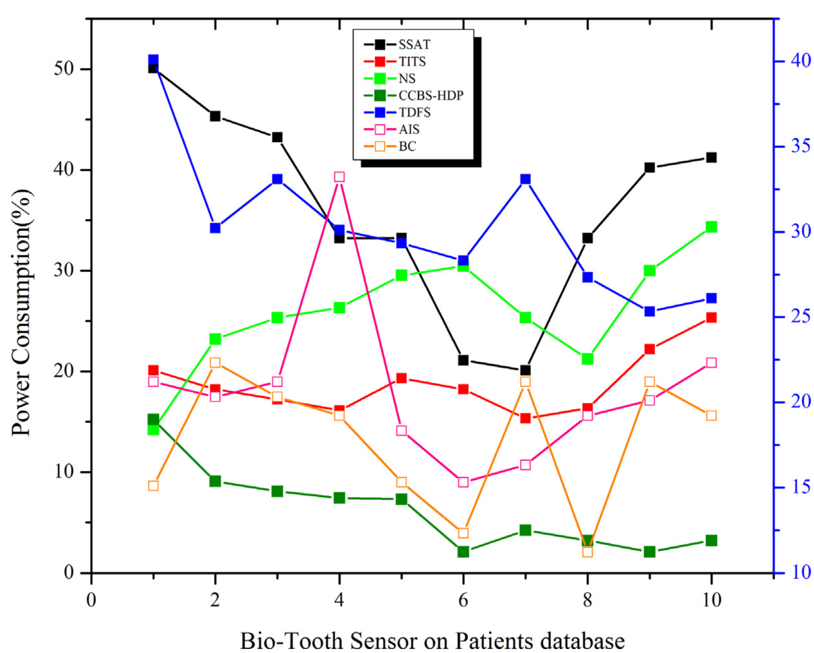

Fig. 7. Power analysis for the bio-tooth sensor with traditional methods.

The linear system has been defined based on the nominal and actual system where the difference among the nominal (N_s) and actual system (A_s) sensor data gives the modeling error (M_e) of the bio-tooth sensor as shown in Eq. (22)

$$M_e = N_s - A_s \tag{22}$$

In this research the transistors When vdd = "ON" which makes the transistor MP2 & MP3 = "ON" helps to reduce the switching activity of the sensor unit in turn reduce the noise factor with high robust and stability. The outcomes are shown in Fig. 9.

The Robust (R) stability of the sensor has been analyzed for various outcomes which is the summation of stable uncertain system ($SS\,(Uu)$) output along with its corresponding transfer function ($Transfer(Fun)$ in accordance with multiplicative model uncertainly ($Ww\,(ss)\forall(ss)$) of the sensor unit as described in Eq. (23), the outcomes are shown in Fig. 10.

$$RR := \{GG\,(ss) \rightarrow (1 + Ww\,(ss)\forall(ss)SS\,(Uu))*(Transfer(Fun))\} \tag{23}$$

Thus the Improved hybridized data processing algorithm for data loggers or data acquisition system with Enhanced digital logic architecture by optimizing SRAM on Novel Crystalline carbon based design development of bio-tooth sensor shows promising outcomes than the existing device available in the markets has been experimentally analyzed for various parameters. This optimized result makes this device more suitable for tooth monitoring in high end medical application.

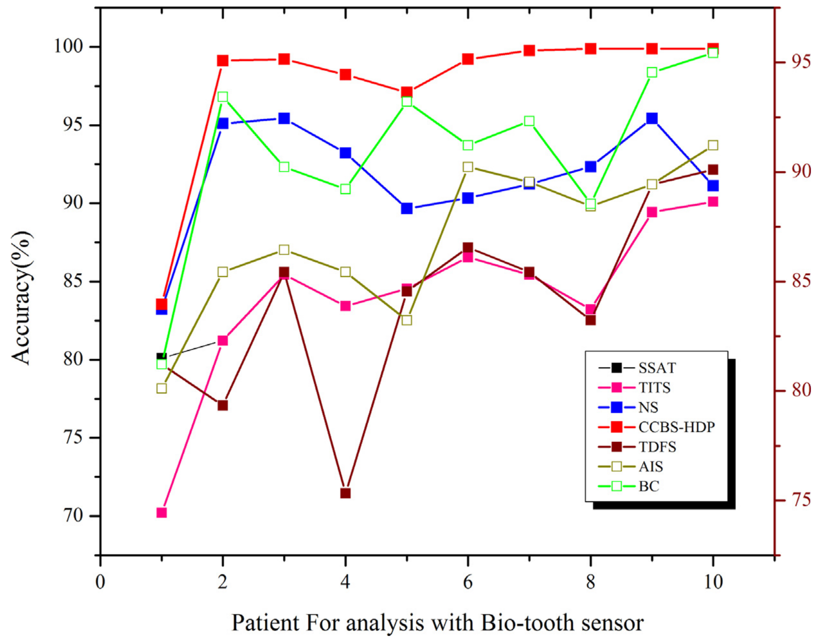

Fig. 8. Accuracy analysis for the bio-tooth sensor.

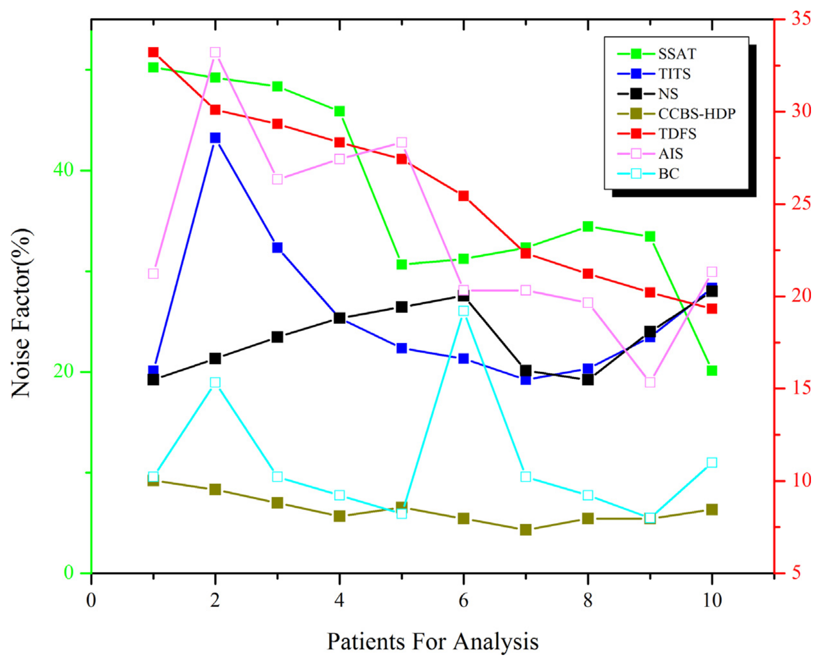

Fig. 9. Noise factor analysis for the bio-tooth sensor with traditional methods.

5. Conclusion and future extension

In this research a tiny ultra-low power and low-cost crystalline carbon bio-tooth sensor with hybridized data processing algorithm has been designed and developed with digital logic architecture that has been placed on tooth platform to monitor mouth and tooth bio-chemical nature which helps to monitor the structural modification instantaneously in turn helps doctors to observe the metabolic alterations in the body. Though various wearable sensors are used in the market to monitor overall health effects and tooth structure, in this research we are much focused on optimizing the required parameters such as noise factor, power consumption, accuracy, efficiency, stability, sensitivity and specificity through proper calibration of sensors and sensitive elements used in the logical architecture shows promising outcomes with 96% efficiency. In future extended research will be planned in optimizing the sensor to miniature scale and advanced machine learning techniques is intended to integrate in this digital architecture.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

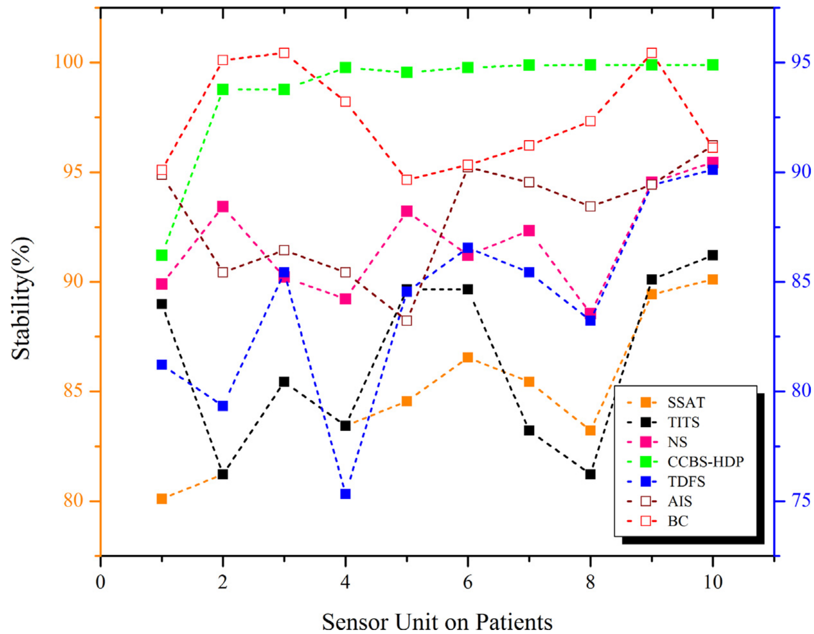

Fig. 10. Stability check for bio-tooth sensor.

Acknowledgments

The authors are grateful to the Deanship of Scientific Research, King Saud University, Saudi Arabia, for funding this work through the Vice Deanship of Scientific Research Chairs.

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