Analysis and monitoring of IoT-assisted human physiological galvanic skin response factor for smart e-healthcare

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Abstract

Purpose – Background: Every so often, one experiences different physically unstable situations which may lead to possibilities of suffering through vicious physiological risks and extents. Dynamic physiological activities are such a key metric that they are perceived by means of measuring galvanic skin response (GSR). GSR represents impedance of human skin that frequently changes based on different human respiratory and physical instability. Existing solutions, paved in literature and market, focus on the direct measurement of GSR by two sensor-attached leads, which are then parameterized against the standard printed circuit board mechanism. This process is sometimes cumbersome to use, resulting in lower user experience provisioning and adaptability in livelihood activities. The purpose of this study is to validate the novel development of the cost-effective GSR sensing system for affective usage for smart e-healthcare.

Design/methodology/approach – This paper proposes to design and develop a flexible circuit strip, populated with essential circuitry assemblies, to assess and monitor the level of GSR. Ordinarily, this flexible system would be worn on the back palm of the hand where two leads would contact two sensor strips worn on the first finger.

Findings – The system was developed on top of Pyralux. Initial goals of this work are to design and validate a flexible film-based GSR system to detect an individual's level of human physiological activities by acquiring, amplifying and processing GSR data. The measured GSR value is visualized "24×7" on a Bluetooth-enabled smartphone via a pre-incorporated application. Conclusion: The proposed sensor-system is capable of raising the qualities such as adaptability, user experience, portability and ubiquity for possible application of monitoring of human psychodynamics in a more cost-effective way, i.e. less than US$50.

Practical implications – Several novel attributes are envisaged in the development process of the GSR system that made it different from and unique as compared to the existing alternatives. The attributes are as follows: (i) use of reproductive sensor-system fabrication process, (ii) use of flexible-substrate for hosting the system as proof of concept, (iii) use of miniaturized microcontroller, i.e. ATTiny85, (iv) deployment of energy-efficient passive electrical circuitry for noise filtering, (v) possible use case scenario of using CR2032 coin battery for provisioning powering up the system, (vi) provision of incorporation of internet of things (IoT)-cloud integration in existing version while fixing related APIs and (vii) incorporation of heterogeneous software-based solutions to validate and monitor the GSR output such as MakerPlot, Arduino IDE, Fritzing and MIT App Inventor 2.

Originality/value – This paper is a revised version R1 of the earlier reviewed paper. The proposed paper provides novel knowledge about the flexible sensor system development for GSR monitoring under IoT-based environment for smart e-healthcare.

Keywords Biosensors, e-Health, sensors, IoT, GSR, Physiological factor, Wearable

Paper type Research paper

1. Introduction

The world has changed dramatically because of globalization of the economy and use of new information and communication technologies, among others. Physiological problems have become a major issue affecting many people of different professions, life situations and age groups. These problems can contribute to illness directly, through its physiological effects, or indirectly, through maladaptive health behaviors. Therefore, these problems urge the need for inclusion of novel solutions which could analyze the human physiological behavior periodically. Galvanic skin response (GSR) is such a technique that measures human emotions by inculcating galvanic impedance on human skin. The GSR falls under the study of Electrodermal Activity (EDA),

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which is defined as the variance in the electrical properties of the skin. The signal can be used for capturing the autonomic nerve responses as a parameter of the sweat gland function.

Several GSR solutions currently exist in the technology domain that perform effective measurement of GSR, for example, Shimmer and BIOPAC MP150. It is a known fact that all available devices are mainly dependent on rigid substrate structure. Rigidity may sometimes affect, as well as resist, the exposure of GSR-monitoring activity. For example, sports, recreational activity, autism patients, military personnel, disastrous victims and emergency. Luckily, flexible substrates are now getting popular for the development of wearable flexible devices (Ghoneim and Hussain, 2015; Torres Sevilla *et al.*, 2014; Kutbee *et al.*, 2016; Emine Tekin and Schubert, 2008; MacDonald *et al.*, 2007). The reasons are multi-fold, such as: (i) inherent consistency, (ii) enhancement, (iii) mediation and (iv) convenience.

This paper proposes to design and develop a GSR-sensing system for managing physiological issues. The envisaged GSR system is developed on a flexible surface to facilitate comfort and high user experience to users. The key idea behind this work lies in the concept of "Flexible Electronics," also known as flex circuits. Table I presents the key abbreviated terms and full forms used in this article.

The main contributions of this study are presented as follows:

- to develop a novel wearable GSR-sensing and signal-acquisition units in more feasible and cost-effective ways;
- to integrate the sub-systems along with a core computation unit by ATTiny85 microcontroller;
- to impose a wireless connectivity by means of Bluetooth Low Energy (BLE) profile; and
- to integrate a whole system on top of a flexible substrate to communicate with a smartphone.

This paper is organized as follows. Section II presents a detailed literature review. Section III discusses the various materials used in system development. Section IV presents the methodology and experimental design. Section V explores the circuit design phases. Section VI presents the test results, validation and discussion. Section VII concludes the paper.

2. Related works

During the survey and review of literature relevant to this system, it has considered previous research performed in the domain of electrodermal activity, human psychodynamics and human emotional instability. Several papers and journals have been referred to gather the resources and the needful knowledge for development of this system. Many researches have been made to practice the emotion or stress detection of human subjects. Apparently, there exists some incompleteness within these research studies that proves the absentia of flexible substrate usage.

We included the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement in the review and selection process of specific articles in the literature review, described as follows. Search for related articles were sought in IEEE Xplore and ScienceDirect digital libraries. Several keywords such as "GSR," "Galvanic Skin Response," "GSR Monitoring," "GSR Measurement," "GSR Flexible Substrate" and "Pyralux GSR System" were used to choose relevant research articles. A total of 371 articles were searched. After removal of duplicate and non-repudiable articles based on correctness and detailed reviews, 57 articles were selected. Out of these, only 24 literatures were chosen for this study. A comparative analysis based on objectives, platform and issues related to each study is presented in Table II. A brief discussion about included articles is presented below. Selected studies could be primarily segregated into four types, based on their applicability, such as:

- stress-detection-based;
- emotional-state-based;
- behavioral-analysis-based; and
- physiological-activity-based.

Table I Abbreviated terms and full forms

Abbreviation	Full form
AHE	Acute hypotensive episode
ANN	Artificial neural network
BP	Blood pressure
BPI	Blood pressure index
BLE	Bluetooth low energy
BT	Bluetooth
CfsSubset	Correlation-based feature subset evaluation
CMOS	Complementary metal oxide semiconductor
CTE	Coefficient of thermal expansion
ECG	Electrocardiogram
EDA	Electrodermal activity
ES	Effort score
FTDI	Future technology devices international
GSR	Galvanic skin response
GUI	Graphical user interface
HRV	Heart rate variability
IAPS	International affective picture system
ICSP	In-circuit serial programmer
IDE	Integrated development environment
IQ	Intelligent quotient
KNN	K-nearest neighbor classifier
MAP	Mean arterial pressure
MIPS	Million instructions per second
OPAMP	Operational amplifier
PANAS	Positive and negative affect schedule
PAT	Pulse arrival time
PCB	Printed circuit board
PPG	Photoplethysmogram
PWM	Pulse width modulation
RBF	Radial basis function
RISC	Reduced instruction set computer
RMSE	Root mean square error
SDNN	Standard deviation of normal-to-normal interval
SVM	Support vector machine
THR	Target heart rate
USB	Universal serial bus

2.1 Stress-based

A Zigbee-based wearable stress-detection system is proposed that measured GSR of 16 individuals as per their activity level (Maria Viqueira Villarejo and Zorrilla, 2012). The experiment

Table II Comparison among related works

Paper	Objective	Sensors, platforms, methods used	Issues related to each implementation
(Maria Viqueira Villarejo and Zorrilla 2012)	To develop a stress-sensing system	ZigBee, Jennic JN-5148 board, WEKA learning machine, sequential minimal optimization, Bayesian network	76.56% success rate was recorded toward mental state detection; pre-trailed participants showed better performance
Bakker *et al.* (2011)	To develop a stress-detection system	Sensor data stream mining, reductionist perspective for stress arousal identification	Data mining algorithm not present; pattern segmentation method not disclosed
(Das *et al.*, 2016)	To identify emotional state of mind	ECG- and GSR-based support vector machine (SVM) approach, Welch's power spectral density domain signal analysis, time domain feature analysis, Savitzky–Golay filtering method, LabVIEW- and MATLAB-based signal analysis, K-nearest neighbor (KNN) classification, video stimuli were given	Happy and sad (i.e. opposite) emotions were most accurately identified; other emotional state conjugations did not give good results; emotion classification was not done
(Zhang *et al.*, 2016)	To recognize public-speaking-anxiety level	Recurrence plot and recurrence quantification analysis, back-propagation neural network algorithm, MP150 physiological response recording system	78.83% performance level was recorded; no algorithmic evidence was prescribed
Fernandes *et al.*, 2014)	To determine stress level	Pulse arrival time (PAT)-based blood pressure (BP) monitoring, PPG and BPI analysis, GSR measurement, ATMega 2560 microcontroller	No evaluation data were mentioned; no comparative analysis was done; no validation of work was prescribed
Tang *et al.*, 2014)	To develop an activity-detection system	Cardio-respiratory sensor, GSR sensor, ZigBee, HRV-EEG processor, AutoSense, Arduino Uno, MCP 6241, ADXL335	No evaluating data were given; schema of the system was missing; no algorithm was prescribed
(Kim *et al.*, 2014)	To develop wearable GSR-sensing system	BIOPAC BN-PPGED, BIOPAC TEL100M, auditory stimuli were given	Only 0.768 correlation was achieved to reference GSR system; sample data were few; methodology was not clarified with conjugation to algorithm
(Subramanya *et al.*,2013)	To develop a wearable system for predicting of acute hypotensive episode (AHE)	Ag/AgCl electrodes, target heart rate (THR) calculation, Bruce protocol, BP and GSR valuation, mean arterial pressure (MAP)	Validation of achieved results was not mentioned; wearable system was not shown in terms of structure; methodology was not clarified
(Rajendra, V and Dehzangi, 2017)	To detect distraction while naturalistic driving	Non-linear space-transformation-based kernel analysis on SVM classifier, radial basis function (RBF) kernel	Only 73.4% accuracy was measured; feasibility study was not conducted; qualitative analysis was missing
(Boon-Leng *et al.*, 2015)	To detect driver fatigue using GSR and EMG	Arduino Lilypad, BLE, LG G Smart watch, Karolinska sleepiness scale (KSS)	Overall accuracy model was not justified; classification of signal response was not clarified
(Healey, 2011)	To develop an e-textile-based GSR sensing system	HTC smartphone, Shimmer sensor, e-textile	Accuracy was not calculated; algorithm was absent; evaluation of deployed system was not present
(Liu *et al.*, 2014)	To evaluate emotional intensity	BIOPAC MP150, positive and negative affect schedule (PANAS), root mean squared error (RMSE), curve fitting	No proof of evaluation was present; sample data selection was not clarified; curve fitting approach was not justified
(Saravanan and Jangir, 2016)	To control bionic arm using GSR	Ag/AgCl electrode, AD620 amplifier, MSP430 G2553 microcontroller	Only 70% accurate control was recorded; no methodological approach was clarified
(Das *et al.*, 2016)	To develop a system to remotely monitor mental effort	Cognitive load score between 1 and 100 was used, ClientUI, Bluetooth, Smartphone, tonic component, effort score (ES)	Statistical validation was not present; feasibility study and reliability assessment were missing
(Sinha *et al.*, 2016)	To analyze mental workload dynamics	Heart rate variability (HRV), standard deviation of normal-to-normal interval (SDNN), intelligent quotient (IQ), tonic power, multiple choice questions (MCQ) were used as stimuli	Detrended fluctuation analysis was not justified; comparative analysis was missing
(Saadatzi *et al.*, 2016)	To develop unobtrusive system for physiological measurement	BIOPAC MP150, BLE, skin conductivity, skin temperature, PPG, ADS1115, LM94022	No evaluation of trials was present; statistical analysis was missing
(Li *et al.*, 2016)	To develop in-vehicle daily health-care monitoring system	MEGA32U4, NRF24L01, Wi-Fi, tribo-element array	Algorithm and feasibility study were not present; comparative analysis was not done

(***continued***)

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Table II

Paper	Objective	Sensors, platforms, methods used	Issues related to each implementation
(Saha *et al.*, 2014)	To develop real-time and virtual stress-monitoring system	LM-741, NI CDAQ 9172, low-pass finite impulse response (FIR) filter	Signaling mechanism not provided; structural analysis was not present
(Yu and Guo, 2015)	To study various physiological classification of emotion	Arousal-Valence space, Plutchik-emotion wheel	No evaluation not methodology was mentioned
(Yoo and Hong, 2016)	To analyze and design emotion signals	PolyG-I device, international affective picture system (IAPS), picture as stimulus, ANN learning, emotion modeling	Algorithmic analysis was not done; GSR reception circuit was not clarified; statistical analysis was not present
(Rivera, 2016)	To develop telematics system for biometric system analysis	4G TELIT Le910 module, e-health sensor platform version 2, ATMega 328, GIS service	Only communication-based network service was discussed; no feasibility study was involved
(Roza and Postolache, 2016)	To develop a citizen emotion-analysis system	Shimmer version 3, SQLite, Smartphone, Google API, emotion classification	Statistical analysis was not present; classification analyzer methodology not present
(Egilmez *et al.*, 2017)	To measure student's subject stress level in colleges	Chest-based heart rate, Android, NeuLog, Polar H7, correlation-based feature subset Evaluation (CfsSubset), random forest	Algorithm was not provided; data-acquisition technique not feasible
(Cabibihan and Chauhan, 2017)	To develop effective telematics system to simulate physiological stimuli	Shimmer, Man Heart Rate Monitor, ATMega 2560, video stimuli	Wearable service was not conformed; hypothetical architecture was provided; evaluation scores were not validated

of stress detection was first carried out on five volunteers to identify the state of mind, e.g. normal, aroused, stressed and relaxed (Bakker *et al.*, 2011). A similar method was used for 25 people between 18-24 years of age to find out their stress values. This approach used blood pressure (BP) and GSR together to point out their mental stress (Fernandes *et al.*, 2014). Conductive-polymer-foam-based GSR-measurement system was developed by Jeehoon Kim *et al.* (Kim *et al.*, 2014), which was tested on four participants. The outcome of this work was in the form of wearable back-attachable sensing system which was validated against an FDA-approved physiological monitoring system. The task of monitoring was carried out through a remote control (Das *et al.*, 2016). Participants had to go through a set of testing methodologies that included video stimulus. In this case, the final results were correlated per effort score (ES) per individual. Stress level in students per subject is different. UStress was designed to cope up the learning mechanisms of such difficulties among the college students (Egilmez *et al.*, 2017).

2.2 Emotional-state-based

Emotion plays a vital role in human life to maintain relationship aspects, be it personal or social. Priyanka Das *et al.* (Das *et al.*, 2016) proposed a solution for the identification of happy or sad emotions, complying with the GSR and ECG values while using the KNN classifier. A GSR-sock that includes fabric electrodes was similarly developed to measure the emotional state of humans (Healey, 2011). A total of 15 human objects were tested in a separate experiment, using a curve fitting technique along with positive and negative affect scheduling (PANAS) mechanism, where emotional intensity was evaluated (Liu *et al.*, 2014). The error rate was measured with root mean square error (RMSE). Emotion was modeled in two and three dimensions (Yoo and Hong, 2016). International affective picture system (IAPS) was applied as the stimuli on the participants. A back-propagation artificial neural network (ANN) model validated their emotional state against an existing solution.

2.3 Behavior-analysis-based

Behavioral assessment is important for understating human's societal interaction. To assist this aspect, several developments were made that used GSR as the key tool. Xu Zhang *et al.* proposed a recurrence-quantification-based analysis strategy to measure the anxiety level of a public speaker (Zhang *et al.*, 2016). Activity awareness was successfully monitored on five healthy human objects (Tang *et al.*, 2014). Time and social factors were primarily solicited while conducting this research. Distracted minds may cause injury while driving. Such behavior was monitored by Vikas Rajendra *et al.* (Rajendra and Dehzangi, 2017). A support vector machine (SVM)-based kernel was used as the wrist-wearable GSR device of six car drivers to investigate the expected output. In an innovative test, a close-eye experiment was performed over 13 students who were asked a set of 40 questions. A GSR-sensing system measured the students' behavioral activities through their pattern of answers (Sinha *et al.*, 2016). Related tests were performed to monitor human behavioral changes per solicited stress levels by incorporating the virtual environment, especially LabVIEW-based simulation tool and 4G LTE internet (Yu and Guo, 2015; Rivera, 2016).

2.4 Physiological-activity-based

GSR-based smart solution was developed to predict that physiological activity mainly relied on blood pressure indexes (BPI) and cardiovascular dynamics (Subramanya *et al.*, 2013). Level of fatigue during driving was tested by Boon-Leng *et al.* (2015) using a GSR device that was strapped on the wrists of drivers to gauge the result per EMG and GSR level. A bionic arm-controlling mechanism was developed that showed the reflexive actions in response to physiological activities (Saravanan and Jangir, 2016). A Bluetooth-based physiological-

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activity-pattern-extraction system – EmotiGO – was recently formulated (Saadatzi *et al.*, 2016). In-vehicle driver's health quality was enhanced with related technology that includes GSR, ECG and smart-posture-detection systems (Li *et al.*, 2016). A completely virtual environment was created to measure human physiological status by means of a low-pass finite impulse response filtering technique (Saha *et al.*, 2014). An effective e-touch-based system was proposed to minimize the stress level of a person through a persuasive touch approach (Cabibihan and Chauhan., 2017). A similar type of video stimulus was given to the participant to measure their responsiveness through a set of sensory and actuation assemblies that were connected through standard internetwork protocols.

2.1.1 Lessons learned
Earlier-discussed research articles mainly focused on the following while carrying out their research:
- more emphasis on analysis of GSR output;
- use of artificial intelligence to infer the outcomes of the GSR output;
- stand-alone system deployment consuming more power;
- use of costly and high-end sensor system to monitor the GSR;
- non-productive infeasible system design; and
- lack of IoT involvement.

2.1.2 Uniqueness of the proposed system
While proposing this article, we consider several novel attributes, as mentioned below, in the envisaged GSR system that makes it different and unique than the existing literature:
- use of reproductive sensor-system fabrication process;
- use of flexible-substrate for hosting the system as proof of concept;
- use of miniaturized microcontroller, i.e. ATTiny85;
- deployment of energy-efficient passive electrical circuitry for noise filtering;
- possible use case scenario of using CR2032 coin battery for provisioning powering up the system;
- provision of incorporation of IoT-cloud integration in existing version while fixing related APIs; and
- incorporation of heterogeneous software-based solutions to validate and monitor the GSR output, such as MakerPlot, Arduino IDE, Fritzing and MIT App Inventor 2.

3. Materials used

3.1 Hardware
The first thing required for this paper was an Arduino Uno and Pyralux. The copper film (acting as a sensor) was connected to the Arduino Uno to measure the GSR. The various hardware used for the development of the proposed system were as follows.

3.1.1 Arduino Uno
The Arduino Uno is the main engine of the deployed system that is an 8-bit microcontroller-based board based on the ATmega328. It has 14 digital input/output pins, out of which some are used as pulse with modulation (PWM) links, six analog inputs, 16 MHz crystal oscillator, a universal serial bus (USB) connection, an in-circuit serial programming (ICSP) header and a reset button.

3.1.2 ATTiny85
The ATTiny85 is a low power-consuming 8-bit microcontroller chip. In this experiment, ATTIny85 was initially attached with Arduino Uno to make it programmable. The following steps were taken into consideration to configure the ATTiny85 to achieve the expected structure. Firstly, fixation of the ATTiny85was was done on the breadboard and then was connected with the Arduino Uno. Next, relevant "ArduinoISP" sketch was uploaded on the Arduino to get it configured as a serial programmer that can program other chips. A 10uF capacitor between the ground and the Arduino reset pin was attached to balance the capacitive reflux. ATTiny85 was subsequently inherited into the Arduino system that was further embarked with a bootloader to make ATTiny85 operable. The final program used in this study was held by ATTiny85. Figure 1 shows the configuration between Arduino Uno and ATTiny85.

3.1.1.1 Pyralux. Du Pont^{TM} Pyralux® is a dual-sided polyimide film bonded to copper foil. It provides hardware designers, fabricators and assemblers a good option for flexible circuit development. Figure 2 presents the layered structure of Pyralux.

3.1.3 HC-05 Bluetooth module
HC-05 Bluetooth uses Bluetooth serial port protocol for transparent wireless serial communication. Master–slave configuration enables HC-05 to get associated with easy interfacing between a computer and its peripheral communicating nodal objects.

3.1.4 OPA4336EA
It is a micropower operational amplifier that is designed for energy-efficient applications. It functions with an operational voltage that is as low as 2.1 V. Besides, being small in size and having a low quiescent current (20μA), it features extremely low offset voltage (125μV max), minimum input bias current

Figure 1 Connection of ATTiny85 to Arduino Uno

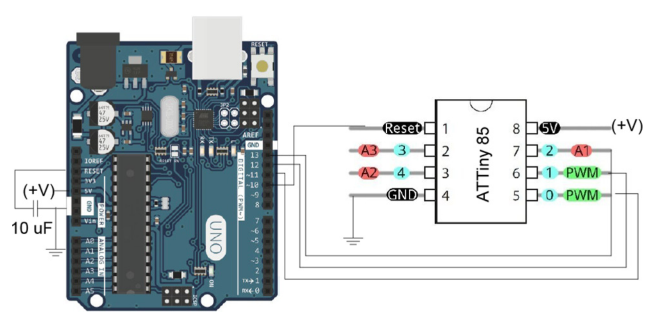
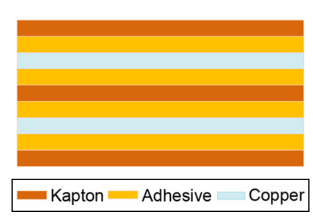


Figure 2 Layers of Pyralux



(1pA) and extremely high loop gain (115dB). Lower crosstalk in interaction makes it suitable for health-care applications.

3.1.5 LM358

The LM358 is used to amplify GSR signals to easily process by the microcontroller. It is an industry standard chip to design the amplifier circuit in biomedical applications.

3.1.6 Miscellaneous components

The other materials used in the system development and testing are as follows:

- *Resistor*: It is a passive two-terminal component that reduces flow of electron in a circuit. The resistors used in the system are of 1M and 330K ohm.
- *Capacitor*: It is a passive device used to store electric charge. The capacitors used in the system are of 10 nF.
- *Oscillator*: It is a passive device used for generation of oscillatory electric signals by non-mechanical means. The oscillator used in the system is of 16 MHz.
- *CR2032 battery*: It is a lithium (Li)-based button cell battery normally rated at 3.0 V. It is commonly used in digital equipment such as wearable devices, electronic calculators, scientific instruments and watches.
- *Copper foil*: It is a malleable and ductile metallic element most often used as a flexible conductor of electricity and thermal energy.
- *Velcro*: It is generally used for fastening a set of different products in industrial and domestic domains that include bag, packaged goods, personal care, apparel and agriculture.

3.2 Software

Different software were used as programming and testing tools for development of the proposed system. The vital ones are discussed below.

3.2.1 Arduino IDE

It is an integrated development environment (IDE) that is used to program and debug AT mega boards such as Arduino Uno, Arduino Mega and their variants. Some third-party hardware platforms are now also being supported by this IDE, such as ESP8266. It contains a programing editor for coding purpose, code-message notification area and a toolbar with a series of multi-functional menus. Mainly, program uploading and error debugging are performed by such IDE.

3.2.2 MakerPlot

It is an application software specifically designed for serial data plotting and visualization. Mainly, its job is to assist in graphical data acquisition and control (GDAC) for providing sensor data from an attached microcontroller to the host computer. It provides preconfigured and custom designs for value meters, control buttons, on/off switches and notification-cum-text boxes that facilitate total control of the graphical user interface (GUI) on the screen. A special tool is also served by the MakerPlot that provides ability to the user for designing a much-needed GUI structure to communicate and plot data coming from microcontroller.

3.2.3 Massachusetts Institute of Technology app inventor version 2

It is an open source software-as-a-service that is hosted on cloud. Its job is to serve services for an Android-supported Web application now maintained by the Massachusetts Institute of Technology (MIT). Such solution gives a graphical programming environment for creation of software applications for Android platforms.

3.2.4 Fritzing

It is an open-source computer aided design (CAD) software platform developed for the formulation of electronics/electrical hardware through simulation, path routing and prototypical model. Professional grade-printed circuit board (PCB) layouts are treated as usual derivatives out of this CAD tool.

4. Methodology and experimental design

The principal task of this system is to detect physiological change and abrupt emotional alteration in human bodies. The idea of biofeedback is adopted to provide individuals with selective information about what is going on inside their bodies.

4.1 System model

One of the user's fingers is connected to the developed flexible GSR system that monitors the physiological parameters and is returned to the user via visualization. The system is designed to be considered as flexible and wearable form factor. The envisaged GSR system model comprises three sub-systems. Signal is originated from the attached sensor patch on a finger of the user. Measured galvanic skin impedance is then acquired, filtered and amplified in a signal-acquisition unit, which is then transferred to the processing unit. The processing unit is made of ATTiny85 microcontroller that assumes the charge of total calculation related to GSR and executes preloaded algorithm to infer the actual information out of it. The next level of signal flow moves toward the user smartphone. The GSR information is transmitted over smartphone by Bluetooth connectivity, which is assumed to be best suitable for such a wearable system. A novel android APP represents the GSR information along with human motion through the expression of graphical and textual modes. The user can control and perform different experiments over the physiological capabilities while visualizing the responses with the help of a clinician. GSR has been used as a key parameter to understand a person's internal state. At this point, it is worth remembering that the aim of this study is to show how a flexible substrate-based GSR-sensing system would work in reality. The logical orientation of the system model is presented in Figure 3(I). It shows that GSR-sensing data are sent to the user's smartphone through Bluetooth. The same has been extended to Figure 3(II) where the following seven components are presented:

- GSR sensor attached on user's finger;
- GSR sensor input-reception circuitry;
- GSR input-signal-filtering circuitry;
- microcontroller assembly;
- Bluetooth controller unit;
- Li-battery unit; and
- user.

Arrow signs present data flow starting from (1) to (7). System-specification details are provided in Table III. The minimalistic

Figure 3 System design of the flexible GSR system

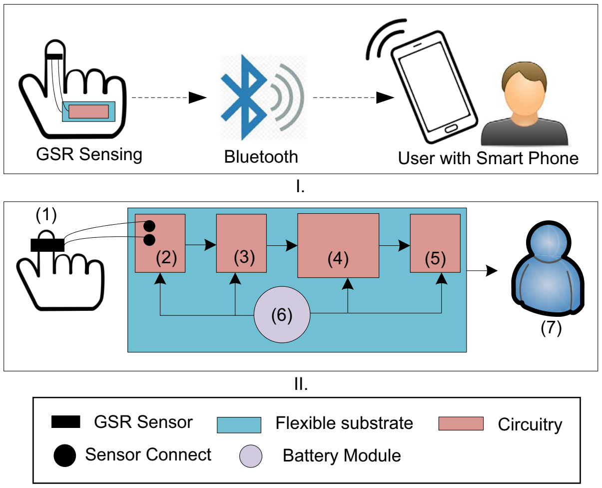


Table III System specification and cost details

Item	Implementation remarks	Cost (USD)
ATTiny85	8-bit AVR microcontroller	2.00
Bt-05	Bluetooth module	2.50
Resistor	1M ohm, 330K ohm	0.05
Capacitor	10 nF	0.10
MakerPlot	MakerPlot V1.7.0 Demo License	Nil
Fritzing	0.9.3 b version Free License	Nil
Kodak Paper	Glossy photo paper 200 GSM	1.00
Pyralux	AC single-sided copper-clad 35 oz	25.00
Valcro	Single-sided patch	0.05
Copper foil	Surface resistance <2 ohm/cm^2	2.50
$FeCl_3$	100 gm powder pouch	1.50
Iron	1000 W, 240 V	10.00
Cotton toil	Ordinary	1.00
Battery	CR2032, 3 V	2.00
PC	Dell Inspiron 4500	Nil
Voltage	3.3-7 VDC	Nil
Power	455 mW	Nil
Minimal total cost		47.70

cost of producing such GSR system was approximately US $47.70. It may be more or less based on the quality of elements.

Algorithm 1: GSR (R) measurement

```
Input: Analog read at port A3

  Output: Galvanic skin resistance

  Step 1: Initialize Bluetooth Server

  Step 2: Set Serial Connection Begin at 9,600
  bps

  Step 3: Read Analog Value (R) from the sensor

  Step 4: If connected to Bluetooth Device

     Send data to mobile app

   Else

     Print: Connection failed

  Step 5: Go to Step 5 until Bluetooth connec-
  tion disconnected

  Step 6: Stop
```

Algorithm 2: Data receiving from the sensor unit to an android application

```
Input: Data read from sensor

  Output: Health status index value repre-
  sented in terms of line graph

  Step 1: Initialize Bluetooth client

  Step 2: Check for Bluetooth connection

  Step 3: If connection available

      Stimuli: Connect to Bluetooth module

     Else if connection not available

      Go to Step 2 (refresh)

     Else

      Go to Step 8

  Step 4: Read GSR data (R) received from the
  system

  Step 5: If (Rm >= Rn + 60)

      Print: Tired

     Else if (Rm>=Rn + 30 and Rm<=Rn + 60)

      Print: Physiological change in activity

     Else

     Print: Normal

  Step 6: Plot data as line graph in canvas

  Step 7: Go to Step 3 until connection
  disconnected

  Step 8: Stop
```

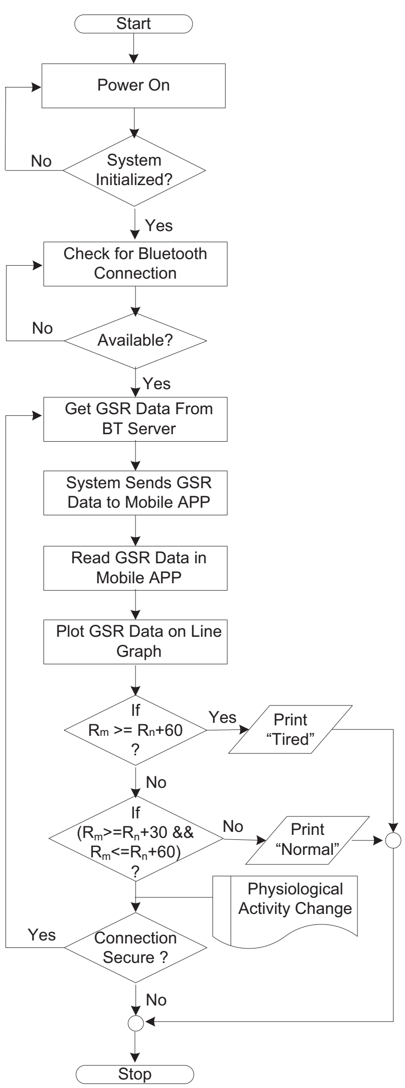
4.2 Algorithm and flowchart

As presented in Figure 3, the proposed system model relies on two key activities: GSR (R) measurement and data transmission over Bluetooth module. These activities are executed in the form of two distinct algorithms, as presented below. First, algorithm fetches raw analog value from GSR sensor node and sends it to the microcontroller through an A3 analog pin for measurement of approximate GSR analog value. It also checks and establishes the connectivity between sensing unit and Android-based smartphone. While implementing this algorithm, serial data rate was set at 9,600 bps. Simultaneously, the second algorithm provides the current state of user's activity level in normal, tired or rapid change of electrical value in physiological level. The output of this algorithm derives the health status index of the user and is shown on the mobile screen.

4.2.1 Flowchart

A flowchart was indeed incorporated with the proposed algorithm, as shown in Figure 4. As depicted, it is clear that upon powering on, the system first gets initialized. Bluetooth connectivity session test is performed just after this stage. GSR value is calculated and health status index is apprehended by the system, which are then transmitted to the connected Android mobile phone via Bluetooth. A graphical plot is presented over the mobile screen. Also, the health status index is printed per current form of physiological condition. This process continues until the connectivity is lost or the system is powered down.

Figure 4 Flowchart of proposed system



5. Circuit design and testing

The design phase of the proposed GSR system can be divided into four parts:

- GSR sensor-design phase;
- GSR circuit-design phase;
- GSR circuit-fabrication phase; and
- Android application-design phase, as discussed in the following.

5.1 Sensor-design process

To design the GSR sensor patch, a 5-cm-wide copper foil was used. The copper foil was cut into two minimized equal strips (i.e. 1.5 cm each) and then attached over the Velcro strap of 5-cm width. Two ends of the copper wires were used as electrodes, such as: (i) GSR I/P1 and (ii) GSR I/P2. These electrodes were kept ready for getting connected to the main circuitry for further processing. The Velcro is to be wrapped around an individual's finger. Thus, the copper foil served as a GSR sensor patch for the proposed system. Figure 5 presents the fabrication process of the proposed GSR sensor patch.

The design process is segregated into eight phases:

- copper foil roll (300 × 5 cm) unpacking;
- cutting a portion of copper foil into two sections, i.e. 18 × 1.5 cm;
- rough upper sides of the foils cleaned with stainless steel brush for removing unwanted dirt;
- upper surface of the foils cleansed and rubbed with ethanol solution to remove static discharges or other dirt;
- super glue is applied to the lower side of the foils and kept left for 30 s to bring tightness. It is then rotated to the upper side;
- foils are placed over a Velcro tape of 21 × 5 cm as per the length and hot-pressed for 1 min by placing a cotton sheet between the iron and Velcro-tape assembly for attaching the foils with the tape strongly 120°C; and
- soldering is done to make the joint points to get attached with both the foils with copper for external wiring to sense the GSR signal, (H) two external copper wires are attached with the foils to make the GSR sensor patch to be completed for further use.

5.2 Galvanic skin response circuit-design process

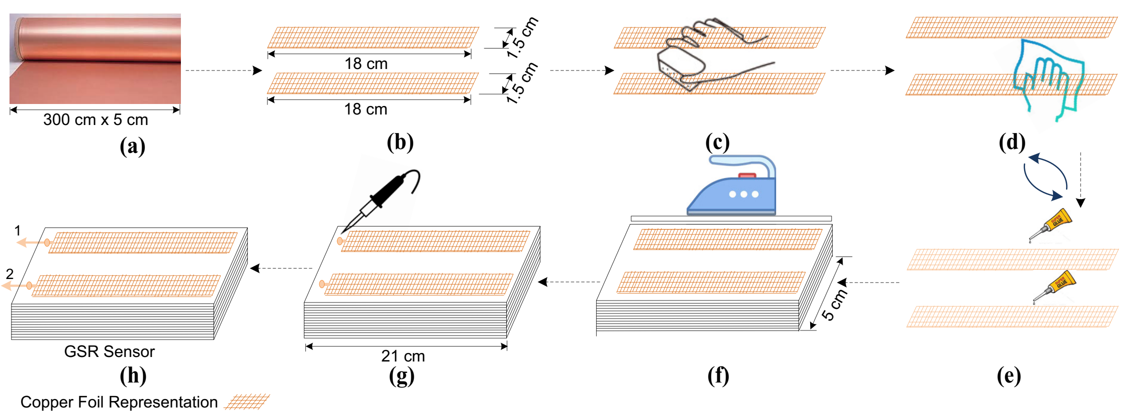
There were several schemas prepared and tested under this study of GSR system, which are referred to in this section. They are classified into three design phases:

- initial design phase;
- intermediary design phase; and
- final design phase.

5.2.1 Initial design phase

The adjustments in this regard are necessary because of dynamic changes in placement of GSR electrodes. A short

Figure 5 GSR sensor patch fabrication process



series of tests was performed with the clothes-peg electrodes (see Figure 5). The resultant analog values were captured with very sharp variations, which were visualized after a few seconds when the user inhaled. Offset resistance is measured as 6K ohm mapped to +5V DC. Later, the tests were modified with more adjustments (Figure 5). The circuitry for the initial attempt of schematic diagram is shown in Figure 6(a). An operational amplifier (OPAMP) OPA4336EA was used in the circuit.

5.2.2 Intermediary design phase

Under a stressful situation, a person normally begins to perspire while reducing the resistance measured between two electrodes, i.e. GSR value. The circuit, as shown in Figure 6(b), acts like a voltage divider. The equilibrium voltage was also set at the intermediate node at 2.5 V by pairing the resistors. Additionally, as this is the only part of the GSR measurement that sends current through the user's skin, it was taken care to choose a moderate upper voltage of 5 V. The user touches the deployed electrodes (i.e. GSR I/P 1 and GSR I/P 2) with the tips of his/her middle and ring fingers.

5.2.3 Final design phase

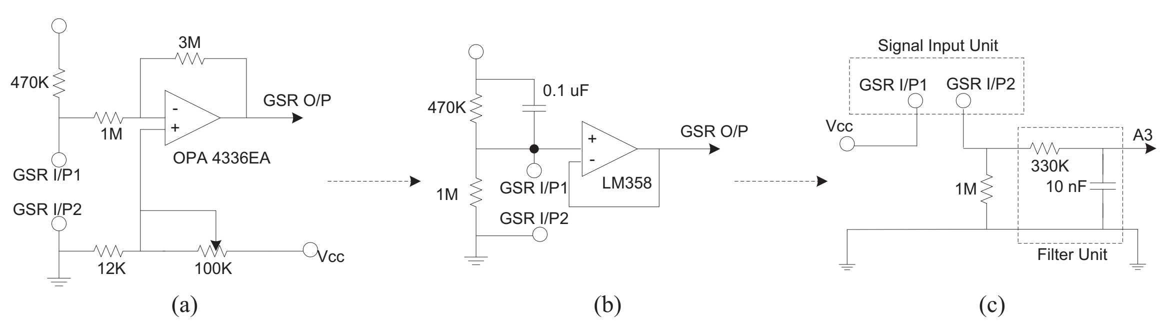
After a lot of in-depth research and tests, a simplified yet effective circuit was illustrated, as shown in Figure 6(c). The circuit facilitates two inputs from the sensors, of which one part of the sensor is situated at the pathway of a power supply (5 V) and the latter goes through a 330K resistor further branched to 1M resistor. The path through 330K resistors end up at analog input (A3) of ATTiny85, which is the input to the system. Another path through 1M resistors leads to the ground of the circuit. The two aforementioned pathways are separated with a capacitor (10 nF).

Figure 7 presents the overall circuit level connectivity diagram of the proposed GSR measurement system. A CR2032 battery set was used to power the system. The ATTiny85 was used as the controller of GSR circuitry. A GSR sensing patch was attached with the aforementioned scenario, as shown in Figure 6(c), which was controlled by ATTiny85. The measured GSR value of health status index was transmitted to the user's smartphone via Bluetooth.

5.3 Galvanic skin response circuit-fabrication process

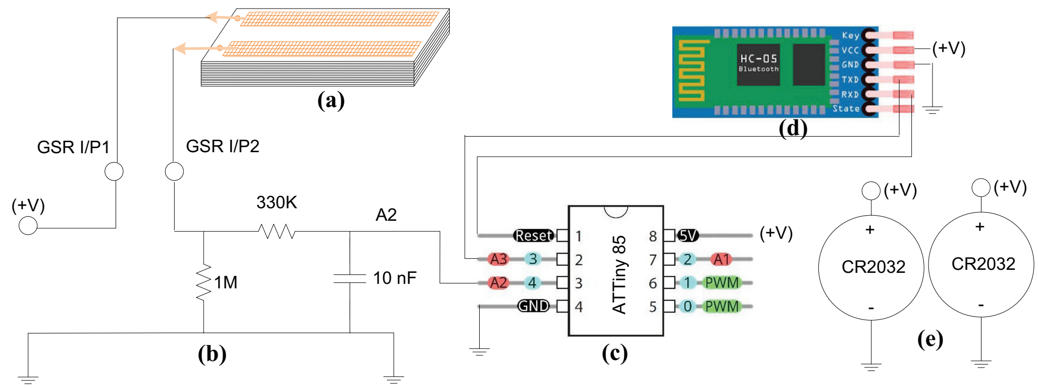
There are two methodologies that can be practiced to develop a flexible PCB: (i) printing a circuit over a flexible substrate using conductive ink and (ii) using a Pyralux. In this study, the second methodology was opted for the development of flexible sensors. A detailed step-by-step methodology is presented in Figure 7, as discussed going forward. First, the final test circuit (see Figure 7) was drawn using Fritzing on a Dell Inspiron 4500 having 8GB RAM, 1 TB hard disk and Windows 8.1 operating system, as shown in Figure 8(a). The resultant circuit was simulated and PCB routed accordingly on Fritzing 0.9.3b. The next step was

Figure 6 GSR circuit-design phases



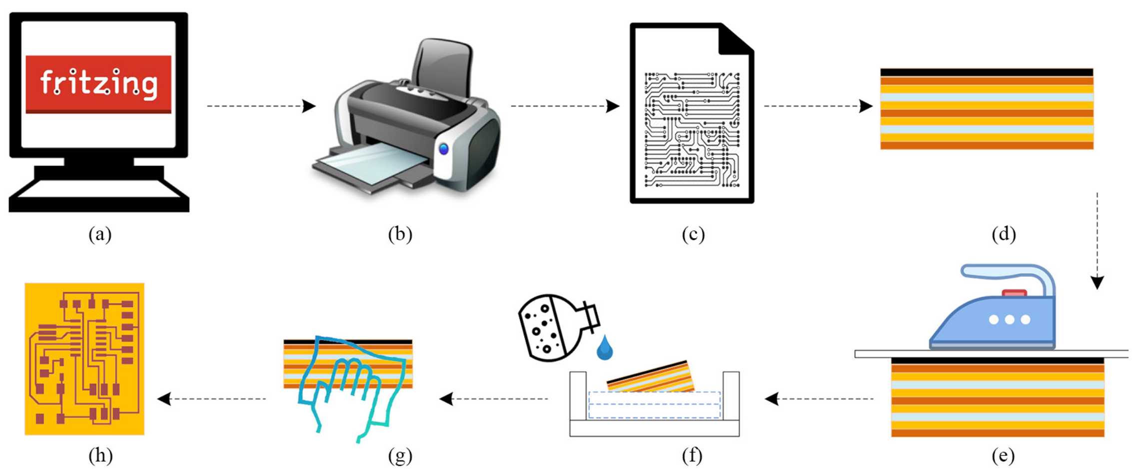
Notes: (a) Initial circuit; (b) intermediary circuit; (c) final circuit showing signal input unit and filtering unit

Figure 7 Overview of GSR circuit interconnection



Notes: (a) GSR sensor patch; (b) GSR reception and filtering circuit; (c) ATTiny85 microcontroller; (d) BT-05 Bluetooth module; (e) CR2032 battery slots

Figure 8 PCB fabrication process



Notes: (a) Circuit design and simulation on Fritzing; (b) printing of circuit schema on photo paper; (c) error checking of circuit drawing; (d) superimposing printed photo paper over Pyralux strip, iron heating process to create adhesion between printed photo paper and Pyralux; (e) etching with FeCl3 solution; (g) etchant removal and cleansing; (h) final PCB on flexible Pyralux substrate

printing the schema of Fritzing circuit on a Kodak photo-quality paper through an HP Officejet 9110 printer, as presented in Figure 8(b). Later, the circuit-schema printed photo paper was checked for corrective measure so that all connections on the circuit were on right place [see Figure 8(c)]. Circuit side of photo paper was then placed over the Pyralux strip per its size and cut accordingly, as shown in Figure 8(d). A cotton sheet was then placed over this assembly and an iron (240 V, 1,000 W) was then used to heat-press the whole thing for 8 min [see Figure 8(e)]. Resultant was a heat-attached sheet of photo paper and Pyralux. It was then cooled down for 5 min. Next step was to etch the unwanted copper clads from the photo paper-Pyralux assembly. For the same, a plastic bowl was used where 200 ml water was dissolved with 50 gm $FeCl_3$ dust. Paper-Pyralux assembly was stirred inside the $FeCl_3 + H_2O$ solution for 10 min [see Figure 8(f)]. This process removed unwanted area of copper clad from the assembly. Later, the assembly was placed inside fresh-water tub to stop further chemical reactions and was soaked in fresh air and cleaned with a fresh cotton [see Figure 8(g)]. The final outcome was a clear PCB over Pyralux, as shown in Figure 8(h).

5.4 Android application development

The Android app was developed, which served as a Bluetooth client, installed on the user's smartphone for reception of GSR value from the deployed system. The application periodically checked for the active connection session, and upon successful connection, the app received mandated data streams plotted in form of the line graph. It also displayed the current physical status of an individual with respect to the data received from the sensor. Figure 9 shows the sample of the graphical output on the Android app (which shows the changes of GSR value in red) for a period of 60 s. The average value per person was

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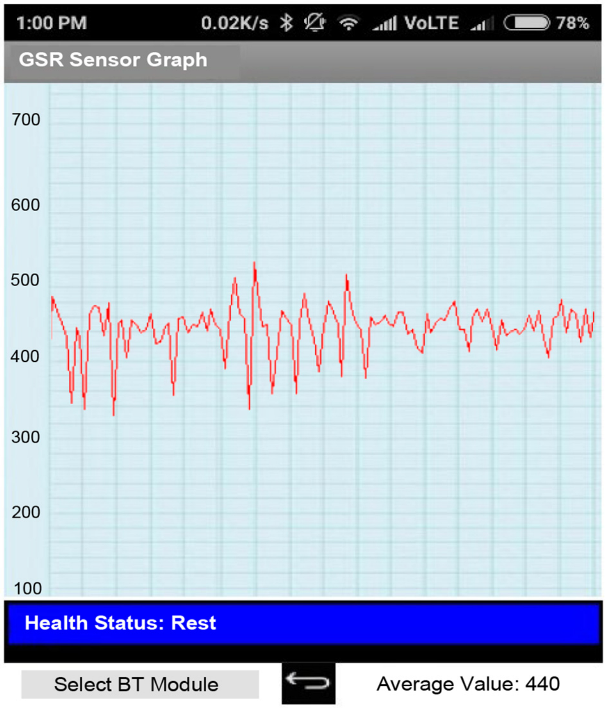
Figure 9 GSR-based graph plotted on the Android app



found to be 440, which was validating the physiological state whether he/she is in rest or normal situation.

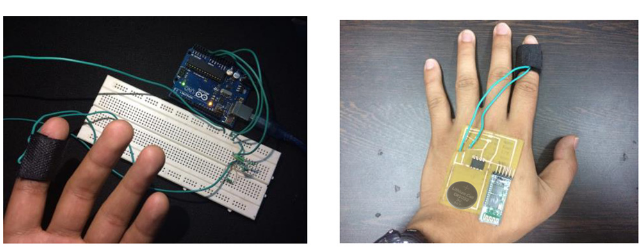
6. Results, testing and validation

The GSR prototype system was designed and tested on a set of 28 volunteers of three different age groups: 11-20 years (17 ± 0.5), 21-35 years (29 ± 0.25) and 36-65 years (46 ± 0.60). This selection was critical in terms of analysis of how different age-group people responded as per their physiological states, including calm or rest and active or unrest, as discussed below.

6.1 Prototype

As a selective outcome of this experiment, several prototypes were designed and tested. Two such prototypes are shown in Figure 10. Figure 10(a) is a prototyping model that was assembled on a breadboard to determine its workability and to observe the results obtained from the GSR system earlier. No

Figure 10 GSR prototype testing



Notes: (a) GSR circuit on breadboard and Arduino Uno (before); (b) final GSR circuit on Pyralux flexible substrate (after)

Bluetooth connectivity was used with it. Upon successful flow of data through the GSR sensor patches and GSR-sensing system, the Pyarlux-based sensor was inferred, as shown in Figure 10(b). The prototype presented herein, integrated ATTiny85 with the Bluetooth module. GSR sensor patch was worn by the user on their finger to collect GSR values. Resistors and capacitors were later added to the prototype, as seen in Figure 10(a) on the breadboard.

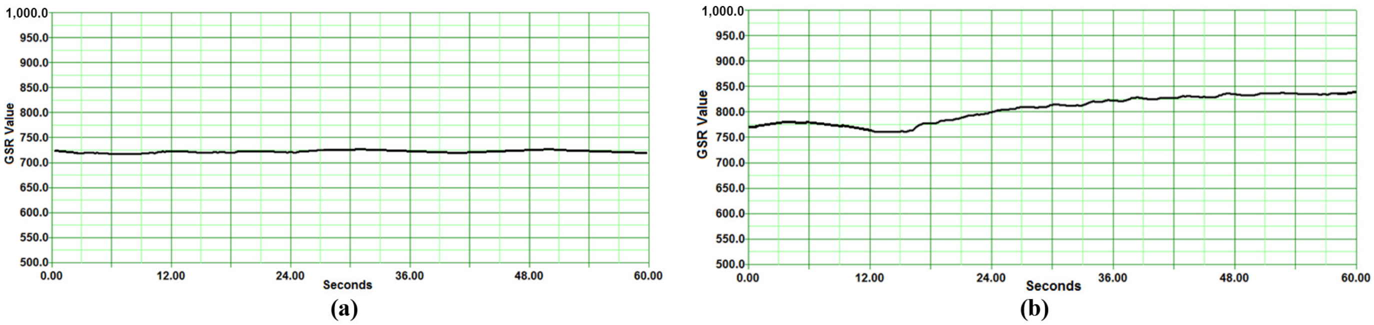
6.2 Test cases

Experiments were performed inside the department's laboratory in a closed room. A total of 28 volunteers, mostly including the department faculty, staff, children and students, agreed to sit for the experiments. Three age groups [11-20 years (17 ± 0.5), 21-35 years (29 ± 0.25) and 36-65 years (46 ± 0.60)] were created for better validation and understanding of the developed system. While conducting the test, each subject was asked to first take physical rest for 15 min. The subject was also told to try not to think more about stressful activities during that period. Later, the sensor patch was worn on the first finger and the subject was asked to keep calm for 1 min. The subject remained silent and kept their eyes closed at the time. The resultant GSR values were received at MakerPlot earlier installed on test PC. Such test was done three times with each subject and the best performance was recorded for analysis. Similarly, each subject was asked to take 10 min of walk inside the department building premises and then sit for the experiment. During the experiment, each subject was told to take a deep breath for 1 min, keeping their eyes open. Figures 11(a) and (b) present the average calm and unrest state values received from age group 11-20 years on MakerPlot. Similarly, Figures 12(a) and (b) present the average calm and unrest state values received from age group 21-35 years on MakerPlot. Lastly, Figures 13(a) and (b) present the average calm and unrest state values received from age group 36-65 years on MakerPlot. It is clearly visible that there is a vivid difference between calm and unrest state GSR values for each age group. Moreover, the average GSR value in two older age groups were more than the youngest age group. The test was repeated with Shimmer version 3 GSR system, which is an FDA-approved device for GSR measurement.

6.3 Statistical evaluation

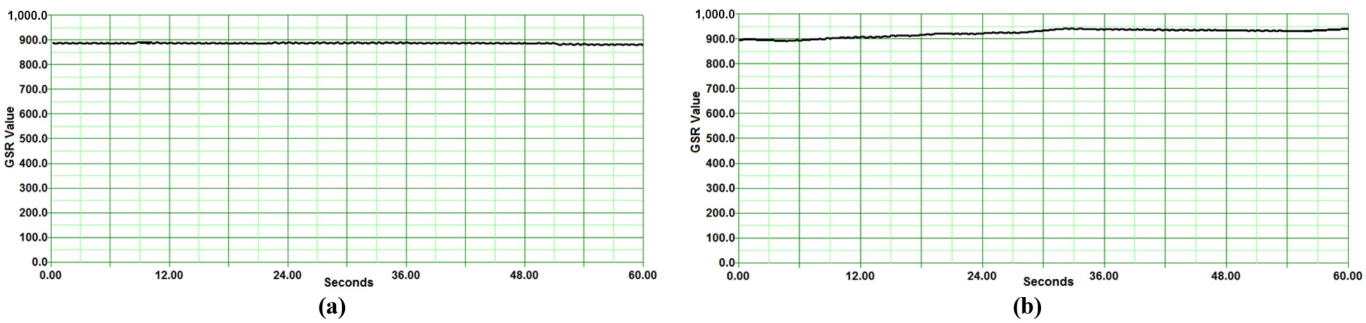
A statistical test was carried out on the captured values from this experiment to prove the effective activity of the proposed system, as shown in Table IV. Table IV shows two test results derived by two methods: proposed GSR system and Shimmer version 3 (per cent). Mean value (μ) and standard deviation (SD) were calculated from the set of collected GSR data. Six participants, from the age group of 11-20 years, sat for the test. Of the participants, 3 were male and 3 female. The average age of this group was 17 ± 0.5 years. The rest and active value difference can be clearly observed between the two test methods. Similarly, 12 participants and 10 participants took the test from the age groups 21-35 and 36-65 years, respectively. The average age of the groups were 29 ± 0.25 years and 46 ± 0.60 years, respectively. The average mean values in rest and active modes were recorded as 823.74 and 817.54 and 868.33 and 853.43 for the proposed GSR and Shimmer version 3,

Figure 11 MakerPlot chart for GSR value among 11-20 years age group



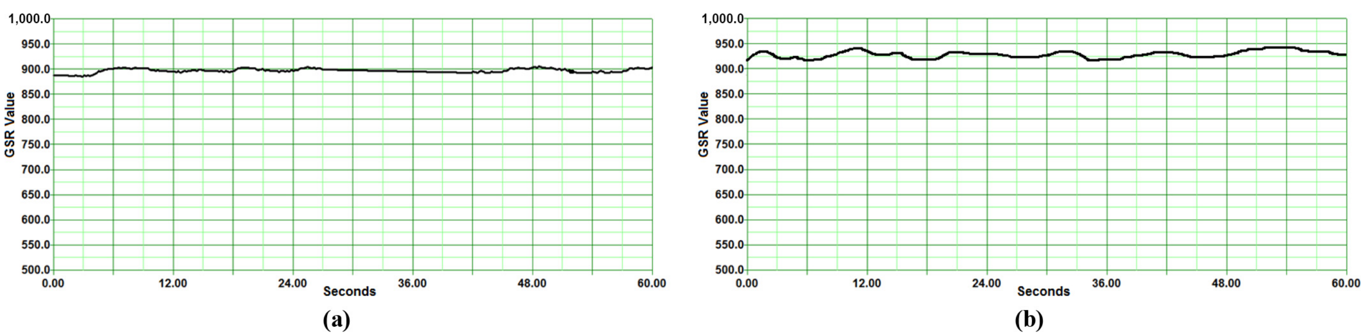
Notes: (a) Calm physiological state; (b) active or unrest physiological state

Figure 12 MakerPlot chart for GSR value among 21-35 years age group



Notes: (a) Calm physiological state; (b) active or unrest physiological state

Figure 13 MakerPlot chart for GSR value among 36-65 years age group



Notes: (a) Calm physiological state; (b) active or unrest physiological state

respectively. In all cases, the male GSR value was more than the female values. Shimmer provided similar output but in a lower value. It is worth mentioning that Shimmer value was ordinarily received in a five-digit format, which was then divided by 100 to present in a percentage format. The reason behind such depreciation was to create a homogeneous environment for comprehending the reactiveness between the two test methods. As the mean and SD values of this test are coherent, no further statistical tests (i.e. T-test or F-test) was performed (Figure 14).

6.4 Comparison against gold standard

We conducted a comparative analysis against the existing *de facto* gold standard, i.e. Shimmer3 GSR (Shimmer3 GSR, 2019). We have considered nine vital characteristics for the analysis:

- flexible substrate use;
- incorporation of IoT;
- use ATTiny85-like small-scale microcontroller;
- APP-based usability;
- system/algorithmic design complexity;

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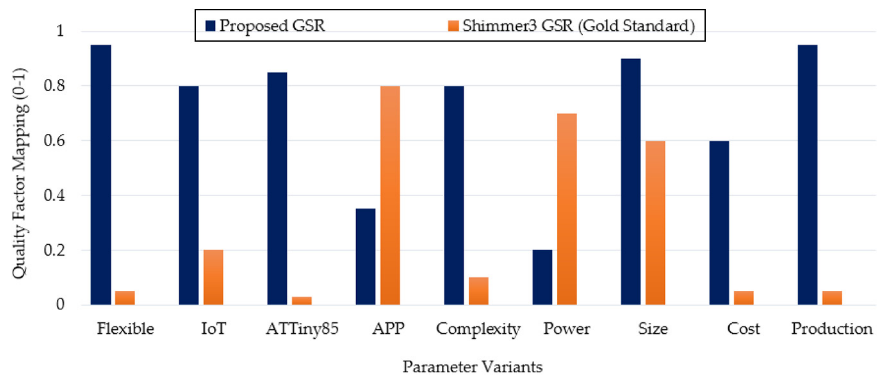
Table IV Statistical analysis of measured GSR

	Proposed GSR-based				Shimmer V3-based (%)			
	Rest		Active					
Age group (No)	μ(R)	SD(R)	μ(A)	SD(A)	μ(R)	SD(R)	μ(A)	SD(A)
11-20 years (6)				17 ± 0.5 years				
Male (3)	725.71	0.10	803.15	0.12	701.35	0.12	782.10	0.19
Female (3)	716.13	0.15	791.64	0.16	697.94	0.11	768.27	0.11
21-35 years (12)				29 ± 0.25 years				
Male (5)	890.10	0.28	912.60	0.14	878.51	0.20	903.70	0.31
Female (7)	873.47	0.71	881.39	0.20	862.93	0.63	869.29	0.34
36-65 years (10)				46 ± 0.60 years				
Male (8)	901.23	0.35	920.61	0.52	892.80	0.30	904.69	0.31
Female (4)	889.83	0.17	900.59	0.67	871.74	0.23	892.57	0.24
Mean value	823.74	0.29	868.33	0.30	817.54	0.26	853.43	0.23

Figure 14 Comparison of parameters with gold standard (Shimmer3 GSR)



- power consumption;
- form factor, i.e. modular size;
- cost-effectiveness; and
- reproducibility by other researchers.

We found that the proposed GSR sensor system outperformed the Shimmer3 over seven different factors, which was mapped within the range of 0 to 1. The proposed GSR system is built on top of the flexible Pyralux substrate, which makes the system flexible, lightweight and portable. The proposed system has the capability to interact with the prospective IoT-based cloud platforms via efficient usage of suitable APIs for further analytics. ATTiny85 is the key inclusion in our proposed GSR that helped to make the sensor-related processing communication with the deployed smartphone-APP easy and energy-efficient. In system design and algorithmic level, our proposed GSR system is better than Shimmer3; the reason is the in-built complexity of jargon elements which may might not have been required for such a device. In this regard, we would append that GSR sensor system is never used for life-saving or accurate disease detection. It is mainly used by patients/medical practitioners to get assistive e-healthcare support. Hence, no such complex design is required for such type of device. Shimmer3 has a larger wrist-worn form factor, i.e. case with wrist band. The resultant size seems to be a bit more than the flexible-compact aspects of the proposed system. The cost of Shimmer3 is around US$480, which is obviously out of reach for many people in developing and underdeveloped nations. The last factor that makes our system better is the reproducibility by other fellow researchers. The design method is clear, with no hidden issues. Shimmer3 is a closed system; thus it has no codes nor designs that can be reproduced. On the other hand, Shimmer3 has better APP support for different platforms such as Android and Apple. It consumes less amount of current 65 μA in active mode, resulting in less power consumption.

6.5 Discussion

The proposed study paves a futuristic way for the development of a novel GSR system while advancing current PCB-based alternatives into a smart flexible ones. The proposed GSR system would be worn by the user on his/her hand. It would then detect and monitor the limits of strength and endurance of the user while considering human physiological instabilities. During the development of the system, a few things were thoroughly challenging:

- enhancement of the flexibility of the PCB was not promising;
- etching of the Pyralux substrate was difficult where novel ideas were evolved and implemented, as mentioned in Figure 8;
- issues regarding communication were encountered when BLE came to the scene; and

- inclusion of CR2032 battery was extremely challenging to provide power to the system. Participant selection was another difficult job to mention.

It was difficult to convince the participants that this system was purely non-invasive and no harm would be done to them. In most cases, some alterations were made to make this system a workable one, such as fabrication process where iron heating was included for the first time for such an experiment. It was quite difficult to measure the exact duration for which the iron would be placed for getting heated. It was also difficult to estimate for how long the Pyralux assembly would be kept for cooling down.

Although this system was tested with promising results, a few things were left that were envisaged to be solved in near future:
- assessment of the oxygen saturation level in the blood of an individual by GSR value;
- monitoring both temperature and sweat gland activity on the hand, using GSR value;
- measurement of user's heart rate from GSR value; and
- approximating the locomotory movement of an individual. One thing that is worth being added with this system in future is IoT (Ray, 2017, 2017a; Ray, 2016).

Upon proper integration with the IoT ecosystem, such wearable device could be used more beneficially to assess human physiological condition and behavior. IoT-based cloud services could be incorporated with the proposed system to store the GSR values so that further data analysis could be performed to learn more details about the mood of the person. It is apprehended that the envisaged outcomes shall leverage a new dimension toward a smarter e-health-supported livelihood experience.

Moreover, the comparative analysis performed between the proposed GSR system and gold standard, i.e. Shimeer3 GSR system, provides valuable information about the user experience and socio-economic aspects. Though Shimmer3 is a popular and *de facto* gold standard for GSR systems, it also has some design- and action-related flaws, as mentioned in the comparative analysis. We may conclude the discussion by mentioning that there is enough scope and opportunity present in the proposed GSR system that could be further inferred and exaggerated to certain development level, where it may surpass the expectations and objectives herein proposed.

We also discuss the related works presented in the recent past where several types of sensors and mechanisms were implemented. Continuous stress and sleep monitoring have been validated and tested by recent research studies (Hovsepian *et al.*, 2015; Lane *et al.*, 2014) where novel sensor methodologies have been implied. Stress monitoring via usage of smartphone is investigated (Lu *et al.*, 2012). Similar work related to wireless skin-response feedback model is conducted using multi-sensor approach (Ouwerkerk *et al.*, 2013; Saleheen *et al.*, 2015). Stress related to catching cold and skin conductance are measured; however, use of IoT is also mentioned in many articles (Ray, 2018; Ray *et al.*, 2017; Silverthorn and Michael, 2013; Storm *et al.*, 2002). Blood pressure is related to stress level; hence, work-space-based stress monitoring has been undertaken in the past (Vrijkotte *et al.*, 2010). Data analytics support via e-governance to solve similar health-related issues is also illustrated (Ray, 2017b) where environment-related factors are considered (Ray, 2016a).

Students often suffer from mental stress; thus, a mechanism should be prescribed to check such GSR levels. Smartphone has been used to cater to this need (Wang *et al.*, 2014). Skin conductance has been measured in some research studies, whereas indirect involvement in relevant areas are mentioned (Ray. 2016b, 2016c; Armel and Ramachandran, 2003). Bionics- and prosthetics-related study is also conducted to seek GSR involvement (Connolly, 2008).

Accidents may occur when the car driver is not fully awake or not concentrating on the road. Mishaps may also occur because of physiological and mental reasons, such as stroke, lack of sleep and tiredness. Artificial intelligence (AI) may be used in the proposed scenarios – (i) to catch the visual perception, (ii) eye movement and (iii) driver's distraction – to assess the actual relationship with the GSR monitoring aspect (Lazzeri *et al.*, 2014; Metz *et al.*, 2011; Young *et al.*, 2011; Wege *et al.*, 2013; Wang *et al.*, 2015; Almahasneh *et al.*, 2014). Further research studies are conducted to check the driver's fatigue, cognitive load, health, electro cardiogram and vital signs, as found to be associated with GSR level (Sieber *et al.*, 2012; Breed, 2014; Jung *et al.*, 2014; Sun and Yu, 2014; Gany *et al.*, 2015).

Extensive research has been undertaken to measure the GSR of human body while implying the eye-blink-based feature-extraction method (Nourbakhsh *et al.*, 2013). Such cognitive orientation is leveraged by Nourbakhsh *et al.* (2012). Investigation was recently conducted to find whether speech analytics could be associated with GSR and, thereby, stress (Kurniawan *et al.*, 2013). Experimental tests over the gait analysis and triboelectricity generation have brought novelties to such GSR application domain.

Dew computing being a novel computing paradigm may be sought for futuristic implementations and solving of e-healthcare and life-risk issues, for example, stress monitoring using GSR sensor system, could be thought of to be able to instantaneously respond to the user-specific queries without dependency on the internetwork backhaul (Ray, 2018a; Ray, 2017c)

7. Conclusion

The proposed GSR system is a fine piece of wearable device prototyped on top of the Pyralux flexible substrate. ATTiny85 and GSR sensor patch were used to develop the system. Associated BLE module conveyed the GSR data in terms of health status index to the user's smart phone, which is accessible through an Android app. A novel PCB fabrication process was tested. The developed GSR was tested on healthy volunteers in a purely non-invasive way, with their consent. MakerPlot was used GSR data plotter tool against the different age groups of participants. A Shimmer3 device was compared against the proposed GSR sensor-system at the same time on the participants. A linear statistical coherence was observed in this experiment. It is envisaged that upon appropriate changes in the proposed GSR, it may further be assimilated with the wrist-watch-type of product. Flexible substrate will surely enhance the user experience to a new level.

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