Non-invasive Analytics Based Smart System for Diabetes Monitoring

M. Saravanan[1(✉)] and R. Shubha[2]

[1] Ericsson Research, Ericsson India Global Services Pvt. Ltd., Chennai, India
m.saravanan@ericsson.com
[2] School of Electronics Engineering, VIT University, Chennai, India
shubharavi20@gmail.com

Abstract. Wearable devices have made it possible for health providers to monitor a patient's health remotely using actuators, sensors and other mobile communication devices. Internet of Things for Medical Devices is poised to revolutionize the functioning of the healthcare industry by providing an environment where the patient data is transmitted via a gateway onto a secure cloud based platforms for storage, aggregation and analytics. This paper proposes new set of wearable devices - a smart neck band, smart wrist band and a pair of smart socks - to continuously monitor the condition of diabetic patients. These devices consist of different sensors working in tandem form a network that reports food intake, heart rate, skin moisture, ambient temperature, walking patterns and weight gain/loss. The devices with the aid of controllers send all the sensor values as a packet via Bluetooth to the Mobile App. With the help of Machine Learning algorithm, we have predicted the change in patient status and alert them.

Keywords: Diabetes monitoring · Non-invasive method · Sensors and devices PSO algorithm · Mobile app

1 Introduction

Diabetes Mellitus kills and disables, impoverishes families, imposes a huge economic burden on governments and business and overwhelms health systems [1]. The healthcare industry is interested in meeting two important goals in a cost-effective way by improving clinical outcomes and enhancing patient care. In order to improve clinical outcomes, real-time measurement and management of illnesses are considered as important features. Providing a better quality of life and user experience to patients is critical to enhancing patient care. IOT in Medical Devices, also known as IOT-MD, promises a cost-effective way to achieve these two goals of the healthcare industry. Connected healthcare programs utilize scarce resources to provide an improved quality of care which leads to better clinical outcomes. Measurable benefits of connected medical devices include reduction in mortality rates, fewer clinic visits, reduced emergency and hospital admissions, including reduction in bed days of care and length of stay in hospitals. Remote monitoring of patients leads to more effective and timely treatment and also it leads to a better management of healthcare [2]. In addition,

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patients (and their relatives) are empowered by getting greater visibility into their actual health conditions, enabling them to play an active role in controlling and influencing their treatment.

Wearable technology, unlike the traditional invasive mechanisms provides continuous monitoring of diabetic people. Basically, there are two ways to provide solutions for the diabetic patients i.e., traditional methods which are invasive in nature and the other one is the more commonly used non-invasive method. Recently, Nanotechnology has come to the fore and contributed in introducing new medical devices in both invasive and non-invasive methods which provide solutions to those suffering from diabetes mellitus. It has paved a way for the invention of Nano Tattoos as well as Nano-based glucose sensors which are used to monitor the glucose level without the need of taking blood samples often [3, 4]. The application of IoT to such Nano-based devices which includes Nanocapsules [5] made the diabetes monitoring even easier. These IoT devices gather patient information from time to time and perform the required processing to provide the information to the patient as well as the doctor/care takers. When addressing such global health issues, one has to provide an end-to-end solution which is cost effective and lasts over a period of time. Bearing all the required features in mind a new non-invasive solution is proposed to monitor diabetic people in real-time.

In the proposed work, a solution is based on three wearable devices, a Smart watch, Smart socks and a Smart neck band which monitors symptoms like frequency of food and water intake, heart rate, skin moisture, ambient temperature, walking patterns and weight. These symptoms are crucial for any diabetic patient and thus, with the data gathered, a stochastic optimization technique is applied on all three devices readings to predict the sudden increase/decrease in glucose level of the patient and thus notify them ahead of time to prevent complication due to diabetes and prevent any fatal effect. Particle swarm Optimization (PSO) [6], a computational method is used here to improve the quality of the solution for real-time prediction. Our system can able to store data for millions of patients to perform analysis in real time, ultimately promoting an evidence-based medicine system.

2 Related Works

In today's world, many devices are available which work with specific methods to monitor diabetic patients. All methods are efficient enough to detect the glucose level but they do lack in certain criteria like performing prediction on real-time streaming data obtained from the sensors attached with the patient's body and provide them with alerts. There are two methods used for diabetes monitoring i.e. invasive and non-invasive. Invasive method uses pricking mechanism that uses blood samples for the detection of glucose level. The existing invasive mechanism for glucose monitoring are Glucose-meter [7] and Gmate Smart [8] which are medical devices that are used for determining the approximate concentration of glucose in the blood. It uses either sensor strips or devices that require blood from pricking in order to determine the glucose level. The detected level is notified to the patient with the help of an app specific to that device. The app based existing monitoring system includes ShugaTrak [9] and Glucose Buddy [9]. Using the app, people with diabetes can easily communicate their blood glucose levels to their loved ones. The apps also incorporate diary for diet, medication, and exercise habit logging. They aim to close the gap between patients and healthcare providers by including the option to have glucose readings sent via e-mail to the patient's medical team. The existing Nano-based non-invasive mechanisms include Nanosensors [4] and Nano-ink Tattoos [4]. The Nano-ink Tattoos are injected into the skin, much like tattoo dye to monitor an individual's blood-sugar level. As the glucose level increases, the "tattoo" fluoresces under an infrared light, telling a diabetic patient whether or not they need an insulin shot following a meal. Smart Sox [10] are designed to identify locations in the foot as well as ranges of motion that could lead to problems. The socks use fiber optics and sensors to monitor changing pressures in the patient's feet. Artificial or Bionic Pancreas [11] is another device in which a signal is transmitted wirelessly every 5 min from a glucose monitor under the patient's skin to a smartphone app. The app will then calculate the amount of insulin or glucagon needed to balance blood glucose, automatically sending a signal to the pumps carried by the user in order to administer the required dose via a tube. CGM [12] is connected to a transmitter that sends the information via wireless radio frequency to a monitoring and display device. The device can detect and notify you if your glucose is reaching a high or low limit. Smart Watches are the wearables that record parameters like heart rate, step count, sleep quality and many such parameters are needed for the monitoring and have to be recorded for a diabetic person [13].

All these existing systems have their own advantages but they do not provide a solution in terms of real-time prediction and early symptom identification [14]. This paper therefore aims at overcoming this limitation to provide end-to-end system which measures all diabetic required features. Moreover, by running the prediction algorithm on the real-time data, the patient can be notified before their condition worsens, thereby decreasing the mortality rate of the human beings. This non-invasive solution when coupled with the real-time information assist in prediction using Particle Swarm Organization (PSO) and help to suggest suitable remedies to diabetic patients is considered as a good model for continuous monitoring and prevention of complications to diabetic patient. In the proposed system, PSO act as a data optimization model in predicting the present status and any serious implications of the diabetes patient from the data collected on three different wearable devices.

3 Proposed Solution

In the proposed solution, we have designed three wearables which include a smart neck band, smart wrist band and smart footwear (or socks) for monitoring the patients and to understand their present condition. The smart neck band comprises of vibration sensors and an array of strain gauges to measure the frequency of food and water intake. Smart wrist band comprises of moisture sensor, temperature sensor and heart rate sensor that provides data about the sweat rate, ambient temperature and the heart rate of the patient. The smart footwear includes pressure sensors and weight sensor which is helpful in determining fatigue and weight. Foot analysis is performed to determine the walking pattern of the patients that gives details regarding the unhealed wounds and other foot complications with few exceptions. All the three modules communicate with a wireless Bluetooth module which transmits the data to the patient's Mobile Phone (or other personal assistants) which acts as a gateway to upload the data to the Health Cloud. By applying relevant Machine Learning and Statistical techniques, the stored data will be analyzed and suitable steps be suggested based on the prediction so as to minimize the effect of complication. Communication layer (Information Processing) present in proposed architecture will be capable enough to send suitable notifications regarding the patient's situation to the concerned doctor at an early stage to avoid the complications in patient's health. We will first explain the details of devices as provided in Fig. 1 and the execution of devices will be explained through a flow chart.

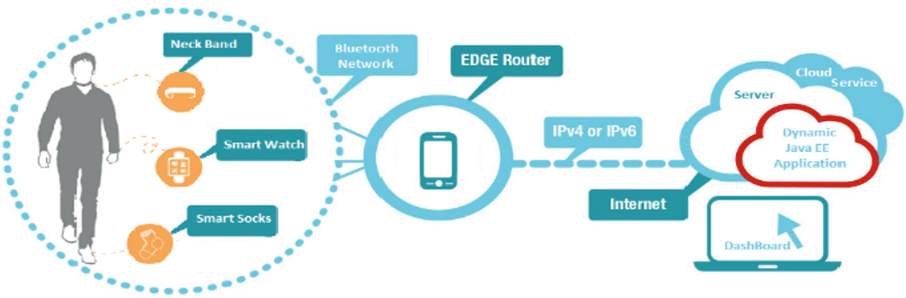

Fig. 1. Overview of the proposed system

3.1 Smart Neck Band

The device consists of a smart neck band which basically monitors two important parameters which are the frequency of food and water intake (polyphagia and polydipsia). The data from the sensor is obtained then passed to the mobile application using a Bluetooth connection then later forwarded to cloud for the purpose of analysis.

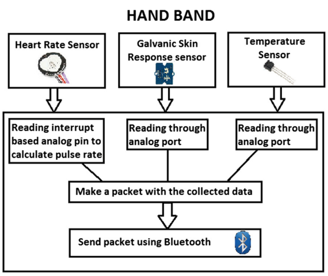

Fig. 2. Smart wrist band

3.2 Smart Wrist Band

It comprises of a smart watch that monitors the heart rate, skin moisture and ambient temperature. Temperature sensor, optical heart rate sensor and galvanic skin response sensor are used to monitor the above mentioned parameters. Temperature is monitored to know the altitude, as the altitude plays an important role in the blood glucose level, when there is an increase in blood sugar level the heart rate keeps fluctuating. Similarly, the skin moisture also varies for diabetic people and data collected from all the connected sensors will be sent it to the mobile application via a Bluetooth so that the data is forwarded to the cloud for storage and prediction. The details are illustrated in Fig. 2.

3.3 Smart Socks

The smart socks consist of pressure sensors and weight sensors. Walking pattern is monitored using pressure sensors placed at pressure points under the foot. The weight sensor detects the gradual weight loss/gain and it is explained in Fig. 3. If the person has foot ulcers the walking pattern will change and the pressure exerted at the ulcer area will vary because the patients tend not to exert pressure in the vicinity of the ulcer. Since the person has polyphagia and polydipsia he might lose/gain weight which can be monitored continuously and can be used to understand the symptoms of the patient.

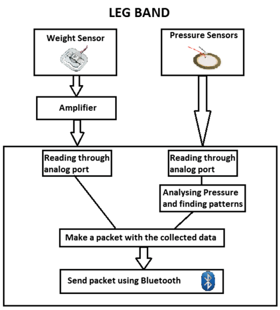

Fig. 3. Smart socks

3.4 Particle Swarm Optimization

In the Particle swarm optimization [6] algorithm, each particle belonging to a swarm, has a position and a velocity (their values are randomized initially). The position with the highest fitness score, in each of the iteration, is set to be the entire swarm's global best (gbest) position, towards which other particles move. In addition, each particle keeps its best position that it has visited, known as the particle's personal best (pbest). The particle dynamics are governed by the following rules which update particle positions and velocities:

$$v_i = wv_i + c1r1(\text{ pbest, } i - x_i) + c2r2(\text{gbest} - x_i) \quad (1)$$

$$x_i = x_i + v_i \quad (2)$$

where x_i is the current position of particle i, pbest is the best position attained by particle i, gbest is the swarm's global best position, v_i is the velocity of particle i, w is a random inertia weight, c1 and c2 are spring constants and r1 and r2 are random numbers between 0 and 1. In this paper, the implementation of PSO is slightly modified and applied to the list of features extracted from three wearables and different embedded sensors to understand the present status of the diabetes patient.

The proposed system is developed with very minimal cost and provides accurate readings with sensors to solve the global health issue of diabetes. This solution can help reduce the world's health expenditure and can help improve the economy i.e. the solution is cost effective and thereby all classes of people can afford such a solution. The main complication of the disease is laid on monitoring, which is overcome by using wearable technologies made with different sensors. When a person with diabetes is continuously monitored, their condition will be under constant surveillance so that any adverse consequence can be prevented in advance. It also predicts the glucose level based on the symptoms exhibited from day-to-day. The data obtained from wearables will be stored on the cloud for future analysis of the patient's condition. The data can thus be accessed by both the doctor as well as the patient.

After processing the data obtained from the three wearables, the coefficient for all three modules is calculated and that is given as the input to Particle swarm optimization (PSO) algorithm. PSO is then applied to predict the present status of diabetes for a specific person. The application of PSO to the list of extracted features of three devices is as follows.

At each time step, the pieces of variable information a given particle (wearable) knows and it can transmit are:

- The current value x_i and the corresponding function value.
- Best position found so far, *pbest* and the corresponding function value.
- Previous position (to estimate its improvement).

Each wearable is assigned a weight along three different axes representing its coefficient. The axes mentioned here are related to the inputs from three wearables and its embedded sensors. Each and every wearable is assigned a position on each axis based on their values in any of the methods. The sum of weights on all the three axes gives the current value of the wearable. Features such as food intake, heart rate, skin moisture, ambient temperature, walking patterns and weight gain/loss are also used to calculate the position of the wearable presence in the model. The wearable's rank is then updated using Eq. (2) which is based on their value. The particles (wearables) are then ranked based on their closeness to the gbest of the swarm. That is clearly explained in the pseudocode given here

Pseudo Code:

```
For each particle {
   Initialize particle
}
Do until maximum iterations or minimum error criteria {
    For each particle
   {
        Calculate Data fitness value
        If the fitness value is better than pBest
        {
            Set pBest = current fitness value
        }
        If pBest is better than gBest

        {
         Set gBest = pBest
        }
    }
     For each particle
     {
        Calculate particle Velocity
        Use gBest and Velocity to update particle Data
     }
}
```

Equation (2) has been used to rank the wearables contribution using the redefined features. Here x_i is the wearable value in the list, v_i is the wearable weight factor which measures of the closeness of the wearable involved to measure the seriousness of diabetes. Pbest, is the wearable best position, gbest, is the best position obtained for the swarm, w is a random inertia weight with value 0.1, c1 and c2 are spring constants with values 1 and r1 and r2 are random numbers with values vary from 0 to 1. The final contribution of wearables is displayed in a ranked manner. Based on the contribution, a prediction is made related to the condition of diabetes of a patient which will be informed to them through Mobile app.

The flowchart shown in Fig. 4 describes the working model of the entire system in which the data is being read from Smart neck band, threshold is set for the module and relevant coefficient value of the module is calculated. Similarly, the embedded sensor values from the other two wearables – the wrist band and socks are read, the threshold for the modules is set and their respective coefficients are recorded. The coefficients relevant to various features will be obtained and these values are inputted to the PSO algorithm to predict consequence of the changes in glucose levels. Here all three device feature inputs will be attracted to the central node which predicts the real consequences. If the respective module's value exceeds the set threshold, individual sensor values are checked to see if their threshold exceeded and thereby the glucose level has increased

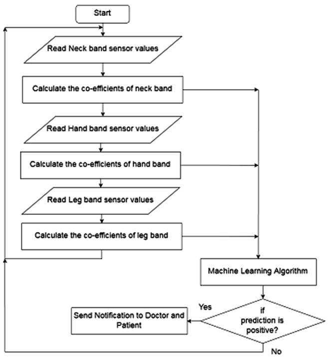

Fig. 4. Flow chart of the system

over a period of time. When the algorithm provides a positive prediction then alert notification will be sent to the patient's mobile.

4 Results and Discussion

The System mainly focuses on supervising the symptoms that a diabetic person exhibits using various sensors embedded in the neck band, wrist band and socks. From the output of neck band, we get to know the food intake quantity so that one can control their blood sugar by managing their diet. Smart socks will specify the possible area where foot ulcer can occur and hence the user can start medication for that area. With the data obtained we can know the current level as well as expected future levels based on the current levels. These results are shown via the mobile app so that the patient can ascertain an increase or decrease in their glucose levels. We have conducted few clinical trials and the results of three different devices sample values are provided here as a result for our experiments.

Smart socks contain pressure sensor to detect the walking pattern depending on the pressure exerted on pressure points. Figure 5 shows the output of pressure sensors. The pressure sensors are placed at the four pressure points of the leg, the spikes in the image describe that even pressure is applied on the pressure points.

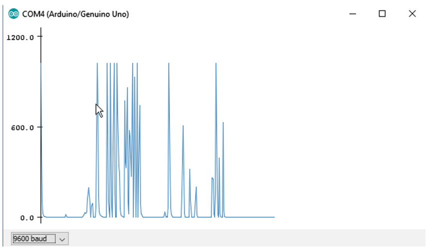

Fig. 5. Output of smart socks device

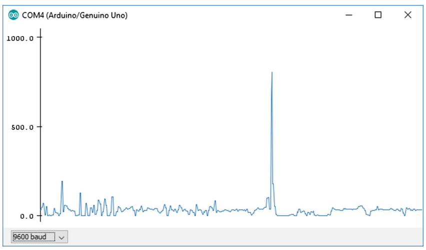

Fig. 6. Output of vibration and flex

Smart neck band detects the frequency of food and water intake. Figure 6 shows the output of neck module i.e. whenever there is a motion on our jaw as well as movement on our throat detected by vibration and flex sensor the output produced would be a high amplitude spike. Smart wrist band is used to monitor the heart rate, moisture content and temperature using sensors. Figure 7 shows the output of smart hand module. The serial monitor is continuously printing the values obtained from the sensor of wrist band such as ambient temperature, pulse rate and skin response.

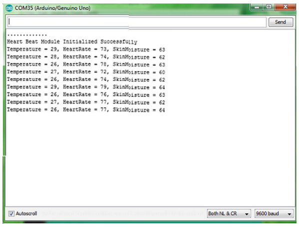

Fig. 7. Output of smart wrist band device

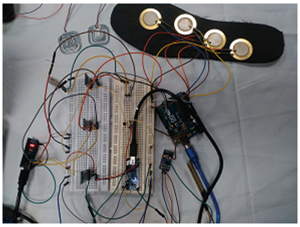

Fig. 8. Interfacing three modules together

The combined circuitry and placement of sensors of all the three modules are made. Figure 8 shows the interfacing of all three wearable modules with the controller and a Bluetooth module to provide the required data. In order to make the mobile function as a gateway, a user friendly mobile app is designed. Figure 9 shows the android app that is developed for the application which has the slot for all three wearables. It will help the patient view his vital parameters at any point in time. The App not only display the vitals but will also have the meal count of the patient and will identify the ulcer location on his foot via the App.

Fig. 9. Mobile application

Diabetes is a major burden to the economy of the world. Globally, 12% of the health expenditure and USD 1330 (ID 1478) per person is anticipated to be spent on monitoring diabetes. Therefore, entire world requires a solution which is feasible, effective and affordable by the common public. From the results obtained for the solution, it's evident that the proposed technology satisfies all the criteria required. The sensors used are accurate and are of low cost. The sensor devices will last over a long period, unlike the disposable strips used in many techniques. The overall manufacturing cost is less and hence even the common public can afford it. As a result, the global expenditure spent per person will be minimized. A system which satisfies all the above constraints is designed and its effectiveness is been proved. Many of the existing systems fail to satisfy the above criteria, all of which are equally important for a healthcare solution. The solution mainly concentrates on providing an end-to-end non-invasive solution for diabetic people using the implementation of IoT-MD and wearable technology while being cost effective. The data from three wearbles is obtained and processing is done to provide the effective output. After the sufficient clinical trials, we found that our solution gives promising outcomes and strongly acknowledge the usefulness of new technology. We also found that the total cost of the entire prototype will be approximately around USD 150 per person.

5 Conclusion

The sudden rise in the number of diabetic patients all over the world and the high cost of monitoring systems calls for innovation in the field of IoT-MD. The application of IOT sensors in diabetics monitoring helped in figuring out the solution for designing wearables using compact sensor devices for the Smart neck band which makes the device weigh less and thereby not be of any hindrance to the patient who uses it. The above proposed system monitors diabetes from the point of view of symptoms a diabetic patient exhibits, that continuously monitor glucose levels using wearable technology. It also emphasizes the advantage of using wearable technology so that a person can know his/her condition at any moment and will get notified about their present status via the mobile app to take precautionary measures to prevent any adverse effects. With further developments, the solution can even act as a patient's care taker as well as a doctor's assisting device.

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