i-SAD: An Edge-Intelligent IoT-based Wearable for Substance Abuse Detection

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***Abstract*—Overindulgence of harmful substances such as drugs or alcohol, called substance abuse, can directly affect a person's health and their day-to-day activities. The younger population become more vulnerable to such use of psychoactive substances due to lack of awareness of the long-term hazardous effects these substances can have on their health. Additionally, these individuals tend to develop severe mental disorders as they grow older. With the boom of Internet of Things (IoT), the use of wearable sensors such as smartwatches and smartphones has tremendously increased. These wearables help in monitoring a person's physiological signal and keep them informed of one's health. In this research, we propose an edge-intelligent IoT-based wearable that can assist in substance-abuse detection by monitoring their physiological signals on daily basis. The proposed system helps in monitoring the substance abuse and craving of the individual and help the healthcare provider to start an early intervention as required. The proposed system is validated using a custom-built wearable, i-SAD, which was developed as a dedicated substance abuse wearable using commercially available off-the-shelf components. The proposed wearable design was validated using medical quality wearable and yielded a correlation of 0.89 for accelerometer values and 0.92 for average heart rate values.**

Index terms— Internet of Things (IoT), Smart Healthcare, Substance Abuse, Edge-intelligent wearable

I. Introduction

A pattern of repeated overuse of any substance such as alcohol or drug, that can directly affect a person's day-to-day activities and health can be termed as substance abuse. Repeated use of these substances can lead to a dependence syndrome which is a cluster of physiological, behavioral, and cognitive phenomena and make it extremely difficult in controlling the use of it. As per the reports of World Health Organization, in 2016, about 27 million people worldwide suffered from overuse of opioids, which are psychoactive substances derived from the opium poppy [1]. Though there are effective treatments for opioid dependence yet less than 10% of the affected population receives treatment. On another report from WHO, it was stated that substance abuse was more common in individuals who didn't have education after their high school. The reason for substance abuse can be a result of anxiety or stress in the person [2].

The Internet of Things (IoT) is a cyber-physical paradigm which helps in connecting real-world devices wirelessly to a virtual cloud, that can advance the computing capabilities of each and every framework [3]. Smart Healthcare is an application of Internet of Things where real-time monitoring solutions can be deployed for healthcare applications [4]. Examples for such applications include activity monitoring [5], temperature monitoring [6], diet monitoring [7], assisted living [8], stress monitoring [9], and so on.

In order to help healthcare professionals to start an early intervention of required treatments in individuals with substance abuse craving, we propose a novel IoT-based edge-intelligent framework for monitoring substance craving. The thematic picture of the proposed framework is given in Figure 1. The proposed framework is a medical wearable that can be used to obtain the vital signs of the individual on a daily basis. By recognizing a pattern in the obtained data, the healthcare professional intervenes at early stages as required.

The organization of this paper is as follows: The novel contributions of this paper are described in Section II. A broader perspective of the proposed iSAD wearable is described in III. Some literature on existing research work on heart rate and accelerometer data along with data analytics is discussed in Section IV. An overview of the system-level modeling of the proposed substance abuse wearable is given in V. The implementation of the proposed design along with a comparison of the accuracy to existing wearables are discussed in VI.

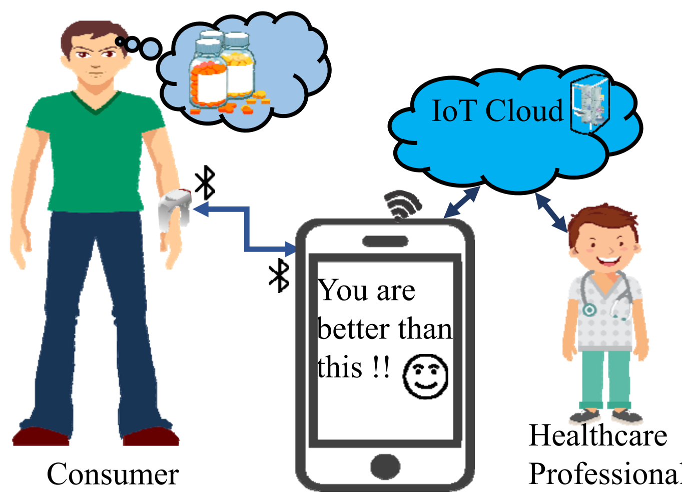

Fig. 1. Thematic Picture of the proposed i-SAD system

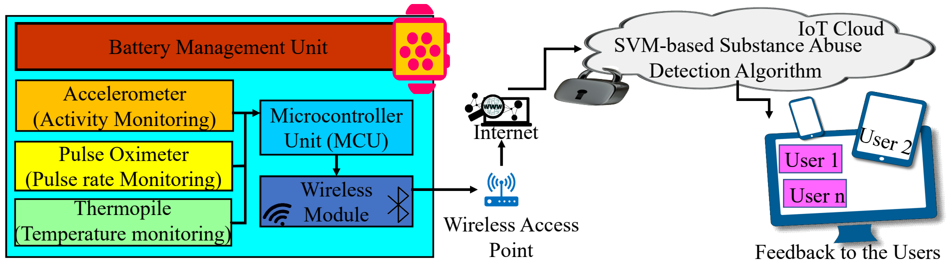

Fig. 2. Overview of our proposed Approach

II. Novel Contribution

This research aims in monitoring substance abuse craving due to stress and craving by using activity data acquired from the proposed substance abuse wearable design. The following are the contributions of this research:

- A novel real-time substance abuse detection wearable has been proposed.
- A novel hypothesis to monitor substance craving due to stress and daily activity has been proposed.
- The proposed design is custom-built using commercially available medical grade off-the-shelf components.
- The acquired data through the sensors of the i-SAD wearable are classified using a support vector machine-based model.
- The proposed design's accuracy is validated using data acquired from FDA approved medical quality wearable.

III. i-SAD for Smart Healthcare: A Broad Perspective

Wearables in the form of smart watches can be easily used on daily basis to monitor one's health. The proposed design for the i-SAD wearable is based on the following hypotheses: *The non-linear features obtained from the activity data associated with the opioid use can help in detecting cravings experienced by the individuals with substance abuse .*
This hypothesis is based on the research on detecting changes in physiological signs during opioid use and during the administration of a specific antidote [10], [11]. To support this hypothesis a dedicated smart wearable system for detecting opioid use based on physiological signals such as gross body movement (activity), temperature, and heart rate is designed and developed. An overview of the proposed i-SAD wearable and the corresponding computations are given in figure 2. Using this dedicated wearable, a healthcare professional is able to monitor a person's physiological signals on a daily basis including user inputs such as stress and craving.

The proposed wearable is built as a light-weight edge-intelligent monitoring system that can run on a powered battery management unit. The sensors of the i-SAD wearable are connected wirelessly to the internet using a microcontroller unit, which can help in scheduling the data acquisition in the device as required. The proposed wearable has some memory capacity that can hold on to the data acquired for a longer time than most of the available wearables.

IV. Related Prior Research

A framework to measure the heart rate using chest-worn measurement unit is presented in [12]. Pandia et al., discuss the artifact cancellation in such chest-worn devices in [13]. Different techniques to monitor heart rate such as using seismocardiography [14], photoplethysmography [15], dynamic movements [16], and so on have been discussed in the respective literature. Researhers have also advocated the significance of combining the heart rate and accelerometer data for emergency interventions in [17]. A method to monitor heart rate variability using accelerometer and gyroscope sensing have also been used in [18]. An intelligent adaptive method for efficient functioning of pacemakers based on accelerometer sensors have been proposed in [19].
Support vector machines have been widely used to classify the healthcare data for various applications [20]. A SVM framework for predicting diseases based on one's lifestye has been proposed in [21]. Chan et al. have advocated a mortality prediction system using SVM in [22]. Researchers have used SVM-based model for predicting various conditions such as on-chip epilepsy detection [23], classiying ear-disorders [24], classification of dementia [25], diabetes [26],lung cancer detection[27], drunk detection [28] and so on. A user-interface based activity recognition have been proposed in [29].

V. System level modeling of i-SAD

The design flow for the proposed i-SAD wearable includes identifying the right sensors for supporting the proposed hypotheses and performing advanced data analytics in the sensor node to detect the substance abuse craving.

A. Design of the Proposed wearable for i-SAD

As the backbone of the proposed hypotheses is in identifying the specific sensors that can help in detecting substance abuse using a dedicated wearable for monitoring stress and substance craving, each and every sensor being used in the design was validated and compared with existing generic wearables. The word "generic" is used here because most of the commercially available wearables monitor an individual's heart rate and activity. But they are not fine-tuned for the given specifications to support the hypotheses. The proposed design for substance abuse detection wearable is given in figure 3. The thermopile used in the i-SAD wearable is for detecting the temperature variability of the individual

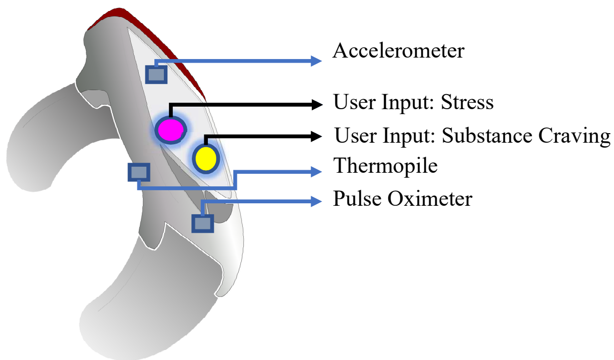

Fig. 3. Proposed Substance Abuse Detection Wearable Design

in given period of time. Hence the temperature values are scheduled in such a way that the current temperature value is being compared with the previously acquired value constantly to check for the rate of change and corresponding variability. The 3-axis accelerometer helps in acquiring the lifestyle activity of a person on daily basis. This is to monitor if the person has reported stress and craving in spite of maintaining an active lifestyle. The pulse oximeter is a medical-grade sensor that helps in obtaining the heart rate of the person on daily basis. In addition to these sensor values, 2 user input values are acquired through the i-SAD wearable. These inputs are stress and craving. i.e., the user records if they feel stressed at a point of time and/or if they have craving for the substance. This user input is recorded along with the timestamp at which the user hits the button.

B. *Features for monitoring Substance Abuse*

The main features for detecting substance abuse are the gross body movement which is recorded as accelerometer values, temperature variability obtained through the thermopile, and heart rate sensor values. Along with this the user input values: stress and craving are used for correlating the obtained features to monitor substance abuse of the person. i.e. if the user records stress or craving, the corresponding sensor values are labeled as ”substance event” and otherwise they are labeled as ”normal event”. If a similar set of sensor values are detected, but there is no user input at a particular time instance, then they are marked for ”vulnerable event”. The healthcare professional periodically reviews this set of sensor values to detect a pattern of substance abuse and craving in the individual.

VI. Implementation and Validation of the Proposed i-SAD System

As the primary goal of the proposed research is to design a dedicated wearable system for monitoring substance abuse, the implementation and validation are focused on testing the reliability of the user inputs and the accuracy of the proposed wearable.

A. *User Input Protocol*

The primary purpose of obtaining the user input at a given time instance is to mark the number of times a person is stressed which might lead to substance craving. Hence the following user input protocol is maintained to effectively derive at the proposed hypotheses based on user input values:

- A simple questionnaire to mark the stress and anxiety levels of the user before using the i-SAD wearable is recorded.
- A preliminary assessment of the substance abuse of the person before using the i-SAD wearable is recorded.
- The user is informed of their accountability in pressing the user input buttons whenever they feel stressed or possess substance craving at any time of the day.
- The user is informed of user rewards such as ”brownie points” that are to be given to the user every time a pattern of healthy active lifestyle is detected. This includes exercising regularly or providing reliable user inputs on stress and craving.

B. *Experimental Setup*

A hardware evaluation was done for each component to design an energy-efficient wearable for substance abuse detection. Table I provides the performance evaluation of the components for energy-efficient design. To maintain overall low power-budget, an optimization at each sensor level and microcontroller level were done to design an energy-efficient design.

TABLE I
Evaluation of Power Budget for Efficient Wearable Design

Component	Typical Draw	Maximum Draw
Accelerometer	0.002 mA	0.011 mA
Temperature Sensor	0.010 mA	0.024 mA
Heart rate sensor	0.6 mA	1.2 mA

After careful analysis of several commercial components, the sensors and microcontrollers were picked for the i-SAD wearable design. Table II gives a detailed list of the components used in designing the i-SAD wearable and their corresponding specifications. The battery management unit offers the following advantages: OverchargeDetection(OVP), Over-DischargeDetection(UVP), ChargeOvercurrentDetection(OCC), DischargeOvercurrentDetection(OCD), LoadShort-CircuitDetection(SCP), in addition to powering up the wearable for more than 10 hours with all its features used at the best. The accuracy of the proposed wearable was validated using a commercially available United States Food and Drug Administration (FDA) approved Medical quality wearable, Empatica E4. The E4 wristband is a wearable research device that provides real-time physiological data acquisition and in-depth analysis and visualization of the same. The E4 wristband can help in monitoring galvanic skin response (GSR), blood volume pulse, acceleration. This comparison was done in order to validate the reliability of the data acquired through the i-SAD wearable.

TABLE II
COMPONENTS USED FOR DESIGNING I-SAD WEARABLE

No.	Component	Purpose	Specifications
1	Accelerometer LIS3DH	To obtain gross body movement	±2g-16g Range,3-Axis Accelerometer, 1-5hz Frequency, 3.3V @ 0.2mA
2	MAX30102 Pulse Oximeter	medical grade sensor that reads oxygen levels and heart rate	Operates at 3.3 V @ 1.5 mA
3	TMP006 Thermopile	obtain temperature variability	3.3v @ 0.240mA, ±1.5°C (max)from–40°C to +125°C
4	LM3671 based 3.3v Regulator + bq297xx Battery Management System	Battery Management Unit	• 3.3v @ 650mA Max Current Draw
5	ESP32 Wroom32U Microcontroller Unit (MCU)	To connect the sensors wirelessly to the internet and support scheduling purposes	Dual core 128Mhz Scalable Processor; Wi-Fi, Bluetooth 4.1, BLE wireless connectivity; 16 MB programable memory, 256k EEPROM; 1 GB MicroSD Card native connector; uFL connector for wireless antenna

Figure 4 shows the comparison of the 3-axis accelerometer values obtained from the Empatica E4 and the i-SAD wearable data. These values were acquired by a volunteer who wore the i-SAD wearable and E4 wristband and performed a similar activity. For a test length of 1 minute, the acquired values yielded a correlation of 0.89 between the sensor values acquired using both these wearables.

Figure 5 shows the comparison of the heart rate values acquired using the E4 wristband and the i-SAD wearable. In the heart rate sensor values acquired from the i-SAD wearable, the beats per minute (BPM) were calculated instead of reading raw sensor data. Using the BPM, a pattern in the variability of the performance of the proposed wearable was analyzed by calculating the average BPM for a given time interval. This average BPM was compared with the heart rate data acquired from the E4 wristband. For a test length of 2 minutes, the acquired wearable values yielded a correlation of 0.92 between the sensor values acquired using both the wearables.

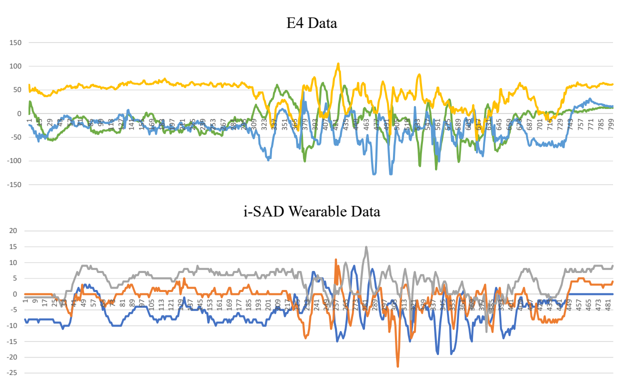

Fig. 4. Comparison of Accelerometer values acquired from the custom-built i-SAD wearable and Empatica E4

After obtaining the initial assessment through the user input protocol, the i-SAD wearable is deployed in real-time. A static casing was used to avoid any short circuit or any hazards in deploying the sensor in real-time. The obtained data was broadly classified into 3 main classes: "substance event", "normal event" and "vulnerable event". A pattern in these events was detected using an SVM-based learning model.

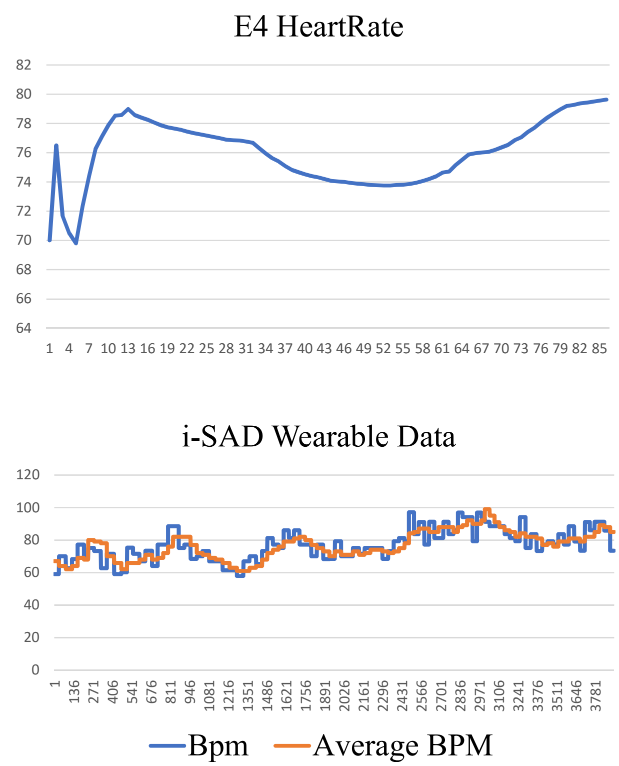

Fig. 5. Correlation of Heart rate values acquired from the custom-built i-SAD wearable and Empatica E4

VII. CONCLUSIONS AND FUTURE RESEARCH

Substance abuse is an alarming issue that can cause lifelong health complications and extreme levels of rehabilitation. The proposed substance abuse detection framework, i-SAD, is a cost-effective edge-intelligent IoT-based wearable that was designed as a dedicated wearable to monitor stress and cravings. The proposed wearable yielded a correlation efficiency of 0.89 and 0.92 when compared to the medical quality wearable. The primary focus of this research was focused on evaluating the proposed framework as an edge-intelligent wearable where all the data analytics were done at the wearable end. Future research includes deploying the proposed wearable in a fully automated IoT wearable and comparing its efficiency with the current edge-intelligent framework. Further, the security and privacy aspects of the proposed research are to be evaluated as part of overall system efficiency.

VIII. Acknowledgement

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References

[1] "Management of substance abuse," World Health Organization, Tech. Rep., 2018.

[2] K. Cherney, "Effects of anxiety on the body," *Healthline*, 2018.

[3] E. Kougianos, S. P. Mohanty, G. Coelho, U. Albalawi, and P. Sundaravadivel, "Design of a high-performance system for secure image communication in the internet of things," *IEEE Access*, vol. 4, pp. 1222–1242, 2016.

[4] P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. K. Ganapathiraju, "Everything you wanted to know about smart health care: Evaluating the different technologies and components of the internet of things for better health," *IEEE Consumer Electronics Magazine*, vol. 7, no. 1, pp. 18–28, Jan. 2018.

[5] P. Sundaravadivel, S. P. Mohanty, E. Kougianos, V. P. Yanambaka, and H. Thapliyal, "Exploring human body communications for iot enabled ambulatory health monitoring systems," in *IEEE International Symposium on Nanoelectronic and Information Systems (iNIS)*, Dec. 2016, pp. 19–22.

[6] P. Sundaravadivel, S. P. Mohanty, E. Kougianos, and U. Albalawi, "An energy efficient sensor for thyroid monitoring through the iot," in *17th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, 2016.

[7] P. Sundaravadivel, K. Kesavan, L. Kesavan, S. P. Mohanty, and E. Kougianos, "Smart-log: A deep-learning based automated nutrition monitoring system in the iot," *IEEE Transactions on Consumer Electronics*, vol. 64, no. 3, pp. 390–398, 2018.

[8] P. Sundaravadivel, S. P. Mohanty, E. Kougianos, V. P. Yanambaka, and M. K. Ganapathiraju, "Smart-walk: An intelligent physiological monitoring system for smart families," in *IEEE International Conference on Consumer Electronics (ICCE)*, 2018, pp. 1–4.

[9] L. Rachakonda, P. Sundaravadivel, S. P. Mohanty, E. Kougianos, and M. Ganapathiraju, "A smart sensor in the iomt for stress level detection," in *IEEE International Symposium on Smart Electronic Systems (iSES)*, 2018, pp. 141–145.

[10] S. Carreiro, K. Wittbold, P. Indic, H. Fang, J. Zhang, and E. W. Boyer, "Wearable biosensors to detect physiologic change during opioid use," *Journal of medical toxicology*, vol. 12, no. 3, pp. 255–262, 2016.

[11] K. K. Chintha, P. Indic, B. Chapman, E. W. Boyer, and S. Carreiro, "Wearable biosensors to evaluate recurrent opioid toxicity after naloxone administration: a hilbert transform approach," in *Annual Hawaii International Conference on System Sciences. Annual Hawaii International Conference on System Sciences*, 2018.

[12] W. Jia, Y. Li, Y. Bai, Z. Mao, M. Sun, and Q. Zhao, "Estimation of heart rate from a chest-worn inertial measurement unit," in *International Symposium on Bioelectronics and Bioinformatics (ISBB)*, Oct. 2015, pp. 148–151.

[13] K. Pandia, S. Ravindran, R. Cole, G. Kovacs, and L. Giovangrandi, "Motion artifact cancellation to obtain heart sounds from a single chest-worn accelerometer," in *IEEE International Conference on Acoustics, Speech and Signal Processing*, Mar. 2010, pp. 590–593.

[14] A. Dinh, Y. Choi, and S. Ko, "A heart rate sensor based on seismocardiography for vital sign monitoring systems," in *24th Canadian Conference on Electrical and Computer Engineering(CCECE)*, May 2011.

[15] H. Fukushima, H. Kawanaka, M. S. Bhuiyan, and K. Oguri, "Estimating heart rate using wrist-type photoplethysmography and acceleration sensor while running," in *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Aug. 2012, pp. 2901–2904.

[16] Yaofeng Wen, Rong Yang, and Yuquan Chen, "Heart rate monitoring in dynamic movements from a wearable system," in *5th International Summer School and Symposium on Medical Devices and Biosensors*, Jun. 2008, pp. 272–275.

[17] D. Curone, A. Tognetti, E. L. Secco, G. Anania, N. Carbonaro, D. De Rossi, and G. Magenes, "Heart rate and accelerometer data fusion for activity assessment of rescuers during emergency interventions," *IEEE Transactions on Information Technology in Biomedicine*, vol. 14, no. 3, pp. 702–710, May 2010.

[18] O. Lahdenoja, T. Humanen, M. J. Tadi, M. Pänkäälä, and T. Koivisto, "Heart rate variability estimation with joint accelerometer and gyroscope sensing," in *Computing in Cardiology Conference (CinC)*, Sep. 2016, pp. 717–720.

[19] Y. Huang and X. Wu, "A method to realize rate-adaptive function in pacemakers based on accelerometer sensors," in *International Conference on Intelligent Computation and Bio-Medical Instrumentation*, 2011.

[20] P. Naraei, A. Abhari, and A. Sadeghian, "Application of multilayer perceptron neural networks and support vector machines in classification of healthcare data," in *Future Technologies Conference (FTC)*, Dec. 2016, pp. 848–852.

[21] M. Patil, V. B. Lobo, P. Puranik, A. Pawaskar, A. Pai, and R. Mishra, "A proposed model for lifestyle disease prediction using support vector machine," in *9th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, Jul. 2018, pp. 1–6.

[22] C. Chan, C. Chen, and H. Ting, "An excellent mortality prediction model based on support vector machine (svm)-a pilot study," in *International Symposium on Computer, Communication, Control and Automation (3CA)*, May 2010, pp. 134–137.

[23] J. Yoo, "On-chip epilepsy detection: Where machine learning meets patient-specific healthcare," in *International SoC Design Conference (ISOCC)*, Nov. 2017, pp. 146–147.

[24] M. Moein, Mohammad Davarpanah, M. A. Montazeri, and M. Ataei, "Classifying ear disorders using support vector machines," in *Second International Conference on Computational Intelligence and Natural Computing*, 2010.

[25] E. E. Bron, M. Smits, W. J. Niessen, and S. Klein, "Feature selection based on the svm weight vector for classification of dementia," *IEEE Journal of Biomedical and Health Informatics*, pp. 1617–1626, Sep. 2015.

[26] A. Mir and S. N. Dhage, "Diabetes disease prediction using machine learning on big data of healthcare," in *Fourth International Conference on Computing Communication Control and Automation (ICCUBEA)*, Aug. 2018, pp. 1–6.

[27] W. Rahane, H. Dalvi, Y. Magar, A. Kalane, and S. Jondhale, "Lung cancer detection using image processing and machine learning healthcare," in *International Conference on Current Trends towards Converging Technologies (ICCTCT)*, 2018.

[28] C. K. Wu, K. F. Tsang, and H. R. Chi, "A wearable drunk detection scheme for healthcare applications," in *14th International Conference on Industrial Informatics (INDIN)*, Jul. 2016, pp. 878–881.

[29] M. Khan, S. I. Ahamed, M. Rahman, and J. Yang, "Gesthaar: An accelerometer-based gesture recognition method and its application in nui driven pervasive healthcare," in *IEEE International Conference on Emerging Signal Processing Applications*, Jan. 2012, pp. 163–166.