M-SID: An IoT-based Edge-intelligent Framework for Suicidal Ideation Detection

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***Abstract*—Suicide is a negative outcome of combination of complex personal, social and mental health factors, which forces the individual to consider it as the only way out to their problems. Suicide has become one of the most significant causes of death in the United States. A major cause of this ominous event is due to mental illnesses such as major depression and bipolar depression. With an aim to increase the awareness of suicide and improve the quality of life of people who are vulnerable or prone to suicidal ideation, this research focuses on developing an IoT-based framework that can help in continuously monitoring physiological and behavioral signals of the individual. The proposed framework, M-SID, is designed based on a hypothesis to capture rapid variation of suicidal ideation using physiological signals. The proposed research is validated with the help of a custom-built hardware and the results are verified using a commercially available wrist band.**

***Index terms*—** Internet of Things (IoT), Smart Healthcare, Affective computing, Immersive environment, Suicidal Ideation

I. Introduction

Suicidal ideation may vary amongst individuals and needs to be addressed differently in every person. Suicidal ideation may be random fleet of thoughts or a more frequent state of mind where the individual actively or passivley thinks about what happens when they are not alive [1]. A major cause of this tragic behavior is mental illness such as depression and bipolar disorder. Individuals who are being depressed or have some sort of mental disturbance, increased social isolation, sudden and unpredictable changes in mood, can be seen as vulnerable people towards committing suicide[2]. Due to the alarmingly high number of deaths due to suicide, research on effectively detecting and diagonising the best predictive pattern of suicidal thoughts, and intervening at the right time has gained a lot of momentum.

Medications and psychotherapy through active and passive methods of intervention with help of technology have been used to treat the underlying psychopathological conditions [3]. Researchers have deployed mobile and sensing technology for real-time detecting, analyzing a pattern for predicting suicidal ideation, and taking immediate care of high risk individuals who are prone to act upon their suicidal thinking and attempt to take their own lives.

Affective Computing is a multidisciplinary branch of science that spans around computer science and Engineering, Psychology, Psychiatry, and neuroscience [4], [5]. Through this experimental methodology, machines have the ability to recognize and interpret the emotional state of humans by detecting emotions from video footage, audio files, text messages, as well as facial expressions, gestures and so on., and stimulate the human emotions through feedback systems. The overall computing effort of affective computing can be broadly classified into two main categories: emotion recognition and emotion elicitation.

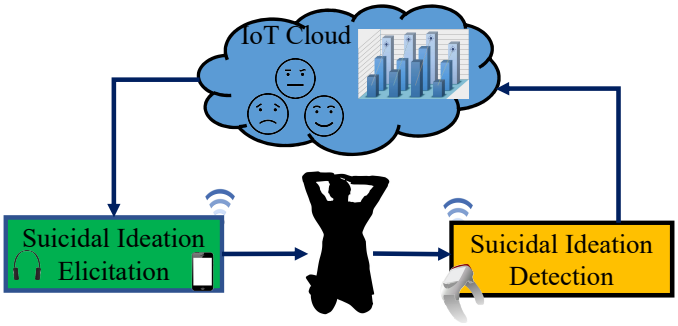

Fig. 1. Thematic Picture of the proposed M-SID framework for Suicidal Ideation

The Internet of Things (IoT) framework helps in connecting simple sensors and actuators to the virtual cloud which helps in performing high computation through these cost-effective frameworks [6]. The goal of this research is to design an IoT-based suicidal ideation detection framework which can help in monitoring and analyzing patterns of physiological signals that can foster early detection and intervention of suicidal ideation. The thematic picture of the proposed M-SID framework is given in Figure 1.

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 M-SID framework is presented in III. Some literature on existing research work on using wearable technology for suicide prevention and methods of intervening is discussed in Section IV. An overview of the system-level modeling of the proposed framework is given in V. The implementation of the designed blocks along with

simulation results are discussed in VI.

II. Novel Contribution

The aim of this research is to design an edge-intelligent IoT-based framework for early detection or prediction of suicidal ideation and deploy affective learning techniques for suicidal ideation elicitation. The following are the main contributions of this research:

- A novel real-time suicidal ideation detection wearable has been proposed.
- A novel hypothesis to analyze the pattern of suicidal ideation has been implemented with the help of custom-built cost-effective wearable.
- The proposed framework helps in making the decisions at the edge-level in addition to developing a pattern in the IoT cloud.
- The proposed design's accuracy and overall system efficiency is validated with help of data acquired from FDA approved medical quality wearable.

III. M-SID Framework for Suicidal Ideation: A Broad Perspective

Though there are many factors that influence suicidal ideation, one of the most common warning signs is experiencing depressed mood or having other mental disturbances. [7]. Affective disorders can be broadly classified as endogenous or reactive. Endogenous affective disorders including major unipolar depression and bipolar disorder are caused by an imbalance in neurochemical/ endocrine/ neurobiological systems in a person's body and needs to be treated by medical model. On the other hand, reactive major depression and adjustment disorders are caused by external factors such as sudden loss of dear ones, financial or professional failure and so on. Symptoms of depression are also a core component in a number of psychiatric disorders such as Premenstural syndrome (PMS), Seasonal Affective Disorder (SAD), Post-traumatic stress disorder (PTSD) and so on.

In the clinical practice, suicide risk is detected and assessed in vulnerable individuals using structured or semi-structured diagnostic interviews and standardized symptom rating scales. However, many suicidal behaviors appear in high-risk individuals suddenly and unpredictably. Detecting rapid variation of suicidal ideation (wish to die or be dead), as a precursor of suicidal act, may be useful in assessing the risk of suicide, however the current clinical practice is insufficient to capture these rapid variation of suicidal ideation which happens over time [8]. There is a need for a wearable sensor system (this is your IoT framework) that can continuously measure physiological or behavioral signals that provide information about suicidal ideation. Such noninvasive system can help clinicians to detect increased levels of suicidal ideation when they occur thereby providing information for the effective management as well as treatment of suicide risk. The proposed framework, M-SID, is built to support the hypothesis proposed by P. Indic et al. in [9], [10] which relates to the emotion and disturbed affect of a person to vitality and psychomotor activity. As per the hypothesis, it has been shown that activity and heart rate data have information about suicidal ideation [11]. Figure 2 shows an overview of the proposed approach. The M-SID framework helps the healthcare professionals to use the individuals physiological signals to analyze a pattern of suicidal ideation and helps in eliciting the emotion in real-time. The proposed M-SID wearable is built as a light-weight edge intelligent monitoring system that is powered up using a battery management unit. The activity and pulse oximeter sensors are connected wirelessly to the internet using a microcontroller unit. The edge-level decisions are achieved using the processor and memory capacity in the microcontroller unit.

IV. Related Prior Research

In an engineering perspective, the use of technology for prevention of suicide has been applied for detection and intervention. Ideally, most of the solutions are based on implementing surveillance to monitor suicide risk, assisted suicide, prevelance of mental health disorders, depression and so on [12]. Research for prevention of suicide has been based on detecting depression [13] or based on crisis of speech [14]. The efficiency of detecting suicides is challenging even for physicians and trained medical professionals as it can be individual specific [15]. In fact, research in [16] shows that upto 66 percent of people who die because of suicide has had contact with their primary-care physician in the month prior to death.

The smartphone based technologies for suicide prevention vary from using mobile apps for intervention and collecting behavioral data from social media and elsewhere to monitor the user's activities leading up to suicide [17]. IoT-based frameworks for various applications including assisted living for elderly [18], monitoring mental health [19], [20], food monitoring [21], [22], activity monitoring [23], women's health [24], and so on. have been developed using off-the-shelf components.

V. System level modeling of M-SID

The design flow for the proposed M-SID wearable includes identifying the right sensors for supporting the proposed hypotheses and performing advanced data analytics in the sensor node to analyze a predictive pattern for suicidal ideation detection. In addition to monitoring suicidal ideation, we explore suicide elicitation methodologies through the proposed M-SID framework.

A. Features for monitoring human affects

An Affect is the descriptive labeling of psychological experience of mood/feelings/emotional states that is conveyed by the person's behavioral expression. A happy affect can be smiling or laughing and similarly a sad or depressed affect might be crying. It is the extremely intense degree and/or

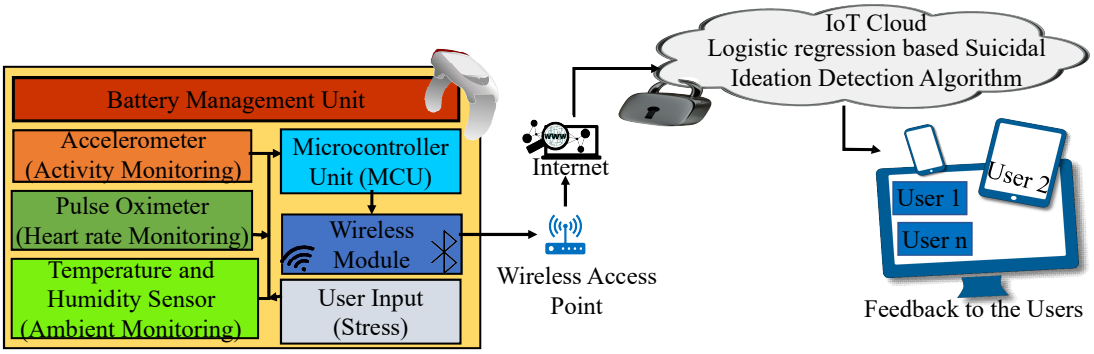

Fig. 2. Basic Block Diagram of the proposed M-SID framework

abnormal psychopathologic transformation of these phenomena, which may indicate the presence of mood disorders. In this research we focus on monitoring human affects related to suicidal ideation with the help of wearables. In addition to the physiological signals, the ambience at which the person resides is recorded to detect the influence of the ambience on person's mood. Table I lists the features used for detecting suicidal ideation.

TABLE I
FEATURE PROTOCOL FOR DETECTING ANXIETY IN M-SID FRAMEWORK

Number	Type of Features
Biosginal Features	
1	Trigger Activity (Accelerometer data)
2	Lifestyle Activity (Accelerometer data)
3	Heart rate
4	Vulnerabilty quotient
Ambient Features	
5	Temperature values
6	Humidity values
7	Season

B. Design of the Proposed wearable for M-SID

As the primary focus of the proposed research is in identifying specific sensors that can help in monitoring suicidal ideation based on the proposed hypotheses, the sensors in the custom-built wearable is carefully selected to meet the requirements of the same. The computing effort is focused on monitoring gross-body movement, heart rate, and ambience of the individual. The custom-built wearable is developed with help of commercially available "generic" sensors which are fine-tuned for the given specifications to support the hypotheses. The proposed design for suicidal ideation detection wearable is given in figure 3.

The temperature and humidity sensor used in the M-SID wearable is for monitoring the ambience of the user in the given period of time. This is done in order to monitor the mood of the person with respect to the ambience. The 3-axis accelerometer helps in acquiring the lifestyle activity of a person on a daily basis. Maintaining an active lifestyle can help in maintaining good health and emotional well-being.

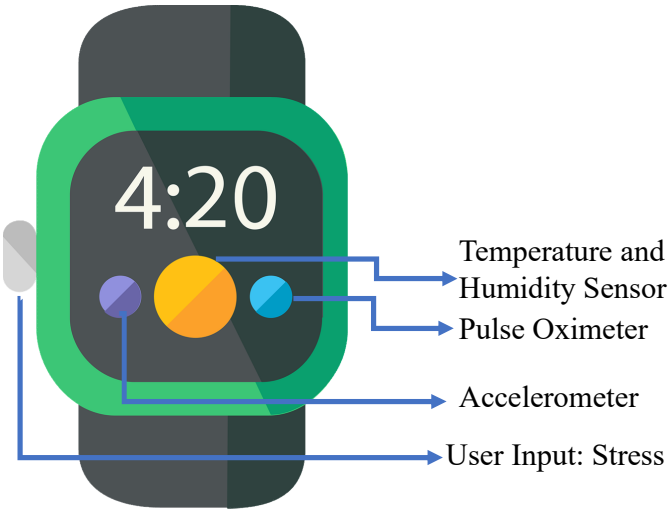

Fig. 3. Proposed Wearable Design for Suicidal Ideation Detection (M-SID)

The pulse oximeter is a medical-grade sensor that helps in obtaining the heart rate of the person on a daily basis. In addition to these sensor values, a user input value is acquired through the M-SID wearable. This is to record the user's feedback on when they are feeling distressed. This user input is recorded along with the timestamp at which the user hits the button.

C. Features for monitoring Suicidal Ideation Detection

The main features for detecting suicidal ideation detection are the gross body movement which is recorded as accelerometer values, heart rate variability obtained through heart rate sensor values, ambient temperature and humidity values, along with the user input value for monitoring distress. The user input value is correlated with the features obtained from the sensors in m-SID wearable to obtain the vulnerability coefficient of the person. The data obtained are labeled as "Vulnerable event", "critical event" and "normal event" accordingly. The healthcare professional periodically reviews this set of sensor values to detect a pattern of suicidal

ideation in the individual.

D. Proposed Methodologies for Suicidal Ideation Elicitation

The proposed M-SID framework advocates building a customized suicidal ideation elicitation methodologies for the individuals using the M-SID framework. The primary focus of the elicitation strategies is to distract the user such that the user can keep their mind off of the suicidal thoughts and lift their spirits up. To achieve this an initial interview is to be conducted to acquire information on user's preferences and accordingly data of either favorite pictures, videos, music and so on are to be collected as part of M-SID database to help with suicidal ideation elicitation.

VI. Implementation and Validation of the Proposed M-SID system

As the primary goal of the proposed research is to design a dedicated wearable system for monitoring suicidal ideation detection and elicitation methodologies, the implementation and validation are focused on testing the reliability of the user inputs and the accuracy of the proposed wearable along with validation of the proposed hypotheses.

A. Validation of Proposed Hypotheses

Figure 4 shows the time-frequency decomposition using wavelet transform of the activity data obtained using the wrist worn devices. As seen in the figure 4 (e) the Vulnerability Index (VI) is the area under the curve obtained from the activity data which can help in detecting suicidal ideation.

Table II shows the correlation of the r and p value which helps in analyzing the VI value in self-reported suicidal ideation scenarios.

TABLE II
Correlations r along with p-value of the feature (VI) extracted from the scaling behavior with the self-reported suicidal ideation

	r	p-value
VI of activity data vs. suicidal ideation	-0.73	0.001
VI of heart rate data vs. suicidal ideation	0.62	0.03

B. 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 in distress which can serve as an indicator for the healthcare professional that the user might have some sort of mental health disorder. Hence the following user input protocol is maintained to effectively derive at the proposed hypothesis based on user input values:

- A simple questionnaire to assess the distress and anxiety levels of the user before using the M-SID wearable is recorded.
- A preliminary assessment of the user's suicide vulnerability and frequency of suicidal ideation of the person before using the M-SID wearable is recorded.
- The user is informed of their accountability in pressing the user input buttons whenever they feel distressed 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 distress and craving.

C. Experimental Setup

A hardware evaluation was done for each component to design an energy-efficient wearable for suicidal ideation detection. To maintain overall low power-budget, an optimization at each sensor level and microcontroller level were done to design an energy-efficient design. After careful analysis of several commercial components, the sensors and microcontrollers were picked for the M-SID wearable design. Table III gives a detailed list of the components used in designing the M-SID 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, and acceleration. This comparison was done in order to validate the reliability of the data acquired through the M-SID wearable. For a test length of 1 minute, the acquired activity values yielded a correlation of 0.89 between the accelerometer sensor values acquired using both these wearables. For a test length of 2 minutes, the acquired wearable values yielded a correlation of 0.92 between the pulse oximeter sensor values acquired using both the wearables.

D. Validation of the proposed M-SID framework

The proposed M-SID framework aims to develop a real-time suicidal ideation detection and elicitation methodology. After obtaining the initial assessment through the user input protocol, the M-SID 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 vulnerability

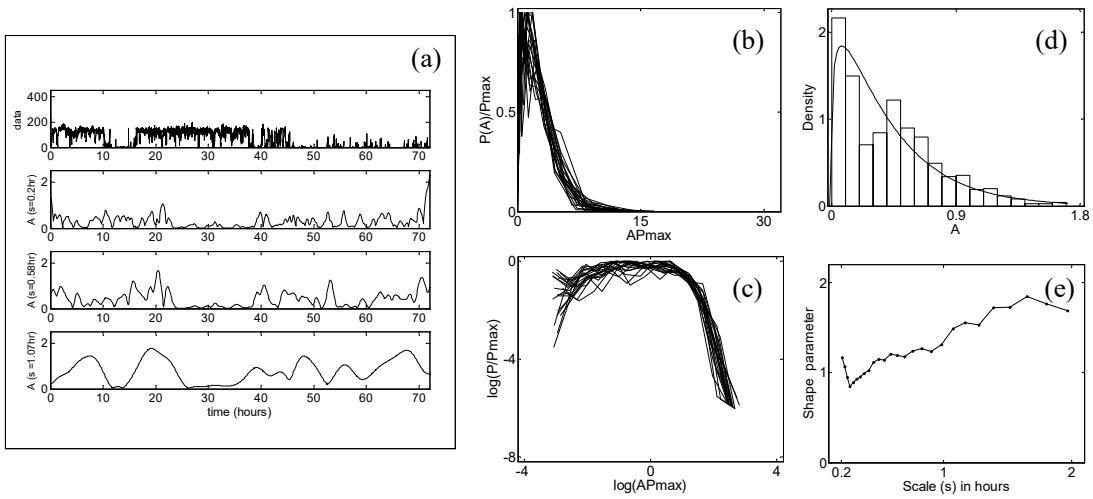

Fig. 4. Activity data obtained using wrist worn device is subjected to a time-frequency decomposition using wavelet transform. The amplitude, A, obtained at multiple time scales shown in (a) exhibit a scaling behavior of distribution of amplitudes (P(A)) shown in (b) has a long tail shown in (c). The distribution at each of the time scale is best fit with gamma distribution shown in (d) to obtain the shape parameter for the scale ranging from 0.2 hours to 2 hours shown in (e). The area under the curve in (e) is defined as a feature called vulnerability index (VI) for activity data is employed to detect suicidal ideation. Similar feature VI for heart rate data (not shown) is also estimated for detecting suicidal ideation from heart rate data.

TABLE III
COMPONENTS USED FOR DESIGNING M-SID 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	Si7021 Temperature and Humidity Sensor	obtain temperature and humidity value of the ambience	3.3v , ±0.4°C accuracy (max)from–10°C to +85°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

Index is obtained with help of advance signal processing algorithms. The data obtained through the M-SID framework is to be broadly classified into 3 main classes: "vulnerable event", "normal event" and "critical event". A pattern in these events was detected using a logistic regression model. Additionally, a correlation related to the season and ambience of the person is to be analyzed for further data analysis.

VII. CONCLUSIONS AND FUTURE RESEARCH

Suicidal ideation and behaviors constitute globally an alarming health-care issue as one of the most significant causes of morbidity and mortality. Continuous real-time monitoring frameworks for suicidal ideation and prevention can help the individuals in need at the earliest. The proposed ssuicidal ideation detection framework, M-SID, is a cost-effective edge-intelligent IoT-based wearable that was designed as a dedicated wearable to monitor mental distress, gross body movement, heart rate along with the ambient values. The proposed wearable yielded a correlation efficiency of 0.89 for activity monitoring and 0.92 for heart rate values 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 analyzing the correlation of ambience and season to further investigate the influence of chronobiological factors and seasonality on suicidal ideation in seasonal affective and anxiety disorders as well as PTSD. 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] E. A. Holmes, C. Crane, M. J. Fennell, and J. M. Williams, "Imagery about suicide in depression–"flash-forwards?"," *Jounral of Behavior Therapy and Experimental Psychiatry*, vol. 38, pp. 423–34, Dec. 2007.

[2] B. J. Mistler, D. R. Reetz, B. Krylowicz, and V. Barr, "The association for university and college counselling center directors annual survey," Association for University and College Counseling Center Directors, techreport, 2014, http://files.

[3] M. A. Ilgen, A. S. B. Bohnert, R. V. Ignacio, J. F. McCarthy, M. M. Valenstein, H. M. Kim, and F. C. Blow, "Psychiatric diagnoses and risk of suicide in veterans," *Archives of General Psychiatry*, vol. 67, pp. 1152–1158, Nov. 2010.

[4] P. Zimmermann, S. Guttormsen, B. Danuser, and P. Gomez, "Affective computing—a rationale for measuring mood with mouse and keyboard," *International Journal of Occupational Safety and Ergonomics*, vol. 9, no. 4, pp. 539–551, 2003, pMID: 14675525. [Online]. Available: https://doi.org/10.1080/10803548.2003.11076589

[5] R. W. Picard, "Affective computing," 1997.

[6] 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.

[7] "Depression and suicide," https://caps.ucsc.edu/resources/depression.html.

[8] E. Basca-Garcia, M. M. Perez-Rodriguez, M. A. Oquendo, K. M. Keyes, D. S. Hasin, B. F. Grant, and C. Blanco, "Estimating risk for suicide attempt: Are we asking the right questions ? passive suicidal behavior as a marker for suicidal behavior," *Journal of Affective Disorders*, vol. 134, pp. 327–332, Nov. 2011.

[9] P. Indic, P. Salvatore, C. Maggini, S. Ghidini, G. Ferraro, R. J. Baldessarini, and G. Murray, "Scaling behavior of human locometer activity amplitude: Association with bipolar disorder," *PLOS One*, vol. 6, May 2011.

[10] P. Indic, G. Murray, C. Maggini, M. Amore, T. Meschi, L. Borghi, R. J. Baldessarini, and P. Salvatore, "Multi-scale motility amplitude associated with suicidal thoughts in major depression," *PLOS One*, 2012.

[11] A. Birkhofer, G. Schmidt, and H. Forstl, "Heart and brain - the influence of psychiatric disorders and their therapy on the heart rate variability," *Fortschritte Der Neurologie Psychiatrie*, vol. 73, pp. 192–205, Apr. 2005.

[12] M. E. Larsen, N. Cummins, T. W. Boonstra, B. O'Dea, J. Tighe, J. Nicholas, F. Shand, J. Epps, and H. Christensen, "The use of technology in suicide prevention," in *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Aug. 2015, pp. 7316–7319.

[13] D. J. France, R. G. Shiavi, S. Silverman, M. Silverman, and D. M. Wilkes, "Acoustical properties of speech as indicators of depression and suicidal risk," *IEEE Transactions on Biomedical Engineering*, vol. 47, pp. 829–37, 2000.

[14] A. Ozdas, R. G. Shiavi, S. E. Silverman, M. K. Silverman, and D. M. Wilkes, "Investigation of vocal jitter and gutter flow spectrum as possible cues for depression and near-term suicidal risk," *IEEE Transactions on BioMedical Engineering*, vol. 51, pp. 1530–40, Sep. 2004.

[15] P. A. Nutting, L. M. Dickinson, L. V. Rubenstein, R. D. Keeley, J. L. Smith, and C. E. Elliott, "Improving detection of suicidal ideation among depressed patients in primary care," *Ann Fam Med*, vol. 3, pp. 529–36, 2005.

[16] J. J. Mann, A. Apter, J. Bertolote, A. Beautrais, D. Currier, and A. Haas, "Suicide prevention strategies: A systematic survey," *JAMA*, vol. 294, pp. 2064–74, 2005.

[17] J. N. Rosenquist, J. H. Fowler, and N. A. Christakis, "Social network determinants of depression," *Mol Psychiatry*, vol. 16, pp. 273–81, 2011.

[18] P. Sundaravadivel, A. Fitzgerald, S. P. Mohanty, and E. Kougianos, "Easy-assist: An intelligent haptic-based affective framework for assisted living," in *IEEE International Conference on Consumer Electronics (ICCE)*, Jan. 2020.

[19] P. Sundaravadivel, V. Goyal, and L. Tamil, "i-rise: An iot-based semi-immersive affective monitoring framework for anxiety disorders",," in *IEEE International Conference on Consumer Electronics (ICCE)*, Jan. 2020.

[20] P. Sundaravadivel, A. Fitzgerald, and P. Indic, "i-sad: An edge-intelligent iot-based wearable for substance abuse detection," in *IEEE International Symposium on Smart Electronic Systems (iSES)*, Dec. 2019.

[21] 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.

[22] ——, "Smart-log: An automated, predictive nutritition monitoring system for infants through the iot," in *IEEE International Conference on Consumer Electronics (ICCE)*, 2018, pp. 1–4.

[23] 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.

[24] 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.