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A Smart Sensor in the IoMT for Stress Level Detection

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***Abstract*—Psychological stress is a sense of pressure which affects the physiological parameters in a person. In this paper a novel stress detection system, iStress is proposed which monitors stress levels through body temperature, rate of motion and sweat during physical activity. The implementation of the iStress system uses a neural network approach utilizing a Mamdani-type fuzzy logic controller with more than 150 instances as the model. The collected data are sent and stored in the cloud, which can help in real time monitoring of the person's stress level thereby reducing risks to health. This system consumes low energy although operating in real time. The proposed system has an ability to produce results with 97% accuracy, low system complexity and moderate cost.**

***Index Terms*—Smart Healthcare, Internet of Medical Things (IoMT), Stress Detection, Borderline personality disorder.**

I. Introduction

Human stress can be broadly classified into eustress, neustress and distress. Eustress is defined as a good stress as it motivates the performance of a person. Neustress is neutral stress and it can be ignored as it does not cause any harm. Distress has negative impact on the human body and is the important factor to focus. Distress is further classified as acute and chronic stress. Short but intense levels of stress in the human body are termed acute while long term intense levels of stress are considered chronic stress [1].

The Internet of Things (IoT) when implemented to medical devices is called the Internet of Medical Things (IoMT). This involves smart on-body sensors, smart gadgets, smart infrastructure, smart homes, emergency response, and smart hospitals that communicate with each other through the IoT. The IoMT plays an important role in real time monitoring, better emergency response, easy access to patients' data, remote access to healthcare and connectivity among stake holders in the smart healthcare framework [2], [3], [4]. Figure 1 shows the concept of the iStress system. The proposed stress detecting system helps in keeping individuals health-aware and maintain emotional balance using smart sensors.

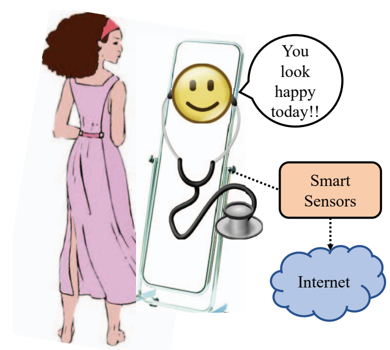

Fig. 1. Conceptual Overview of the iStress System.

The paper is organized as follows: Section II discusses the novel contributions of this paper. Section III discusses existing related research. A detailed explanation of the proposed research is given in section IV. Section V discusses the proposed novel approach for accurate analysis of the state level. Section VI validates the model with implementation results of the proposed system. The paper is concluded in section VII

II. Novel Contributions

The **novel contributions of the current paper** can be summarized as follows:

- A novel approach using Mamdani fuzzy logic for accurate stress detection from physiological activity is presented.
- The proposed approach combines the body temperature, rate of motion, and body sweat to accurately and quickly detect stress, while existing approaches discussed in Section III use only single parameter.
- A novel sensor that uniquely quantifies the body temperature, rate of motion, and body sweat accurately and quickly to detect stress level is presented.

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- A novel IoMT-enabled system for stress analysis at the edge and not at the cloud is proposed, thus advancing the state-of-the-art in the IoMT.

III. Stress Detection Approaches: State Of Art

A group of games that integrate biofeedback processes is used in [5] to relay physiological inputs which are collected through biological sensors. These physiological inputs are converted to measurable parameters that indicate the status of the stress levels in individuals. Wearable sensors along with mobile phone usage such as call, text, etc., are used in [6] to recognize stress. Stress monitoring using the respiration rate is presented in [7] where computer vision methodologies are implemented. Optical flow in a video sequence is used to measure the periodic motion of the chest wall. Mental stress is monitored using the linguistic outputs of a person in [8]. Fuzzy logic is used in determining the outputs of the linguistic model. Three individual stress tests were made with a wearable system which used Electrocardiogram (ECG), respiration, skin conductance and surface electrocardiogram (sEMG) in [9]. Mental stress is detected using an analysis of heart rate variability in [10] where a non-linear system identification technique, called principal dynamic modes (PDM) is used to analyze stress. Stress monitoring is done using headphones wherein a small device is incorporated which continuously monitors the ECG, impedance and acceleration of the head in [11]. However, this method requires continuous contact of the headphones to the body. A machine learning based approach using functional MRI (fMRI) to identify borderline personality disorder has been proposed in [12]. In this work, spectral power features are extracted from spectrum power density and cross spectral density of resting stare fMRI data.

IV. The Proposed Novel iStress System for IoMT

A. Proposed Novel Architecture

Figure 2 shows the overall architecture of the iStress system. A machine learning approach is implemented in order to find the stress of a person. Once detected, stress is categorized as low, normal and high. Using a Wi-Fi module, the system is connected to the cloud which is used to store present and previous stress levels at certain intervals.

B. Sensors For Stress Analysis

1) Temperature Sensor: In general, temperature sensors can be grouped into contact and non-contact sensors. In this research we modeled a contact temperature sensor which can follow rapidly the rate of variation in body temperature.

2) Humidity Sensor: Humidity sensors are used to analyze the variation in sweat secretion, which is related to the central nervous system. These sensors are mainly used in finding the stress levels and the arousal levels of the human body based on the sweat generated. Sweat gland activity as a variable is used in many biofeedback applications such as lie detection,emotion recognition, etc. [13], [14].

3) 3-Axis Accelerometer: The accelerometer sensor measures the rate of change in velocity of an object . It is measured in meters per second square (m/s^2). Accelerometer sensors are widely used in smart phones, gaming, solving diverse problems, fall detection, users' activity recognition, location identification or even to count the human body movements, number of steps, uphill, downhill, etc.

Figure 3 presents an overview of the iStress system. iStress follows a new methodology in detecting the stress of a person. The machine learning approach is explained in detail in Section V. The stress detected is classified as low, normal and high. The sensor data are calibrated and assigned to binary 0 and 1. This assigned data are given as the input to a Mamdani fuzzy logic controller used to determine the stress level of a person.

V. The Proposed Novel Approach for Accurate Stress-Level Detection

The proposed iStress system shown in Figure 2 is modeled using humidity, accelerometer and temperature sensors. The sweat rate of a person can be generalized using gravimetric measurements [15], [16]. As the number of steps taken by a person increases, the stress increases. The general step rate of a person in an immense physical workout is considered to be high if it is greater than 100 steps per minute [17]. When a person is not stressed and is in normal condition the proposed accelerometer sensor value is reduced to 50 steps per minute. The lower the temperature of the human body, the palm portion of the hands becomes cold. Colder palms are a symptom for the person under stress [18].

The fuzzy logic based analysis used is helpful in extracting meaningful knowledge from the given inputs and outputs. It has high tolerance to uncertainties and represents the output with no loss of accuracy. In this paper, a Mamdani-type fuzzy type controller is constructed. The inputs can be many but the output is limited to one. Using the grid partitioning method, the rules with which the input and output are related are generated [19]. The Mamdani-type controller is a system which is obtained by synthesizing a set of linguistic control rules taken from experienced human operators [20], [21].

The logical operation of the sensor values of the iStress system can be analyzed in terms of a truth table. When the sensor values are low, the output stress is low and is denoted by logic 0. When the inputs are all high, the stress level is defined as high stress and is denoted by logic 1. A pictorial representation of the fuzzy operation is given in figure 4.

VI. Design and Validation of iStress

A. Software Based Design Validation

1) Sensor Calibration and Controller Characterization: Table I gives the range of the sensor values classified into 3 levels of stress: low, normal and high.

The sensor outputs were fed to a fuzzy logic controller designed in MATLAB® [22], [23], [24], [25]. An open source sensor value dataset is used as the input to the fuzzy logic.

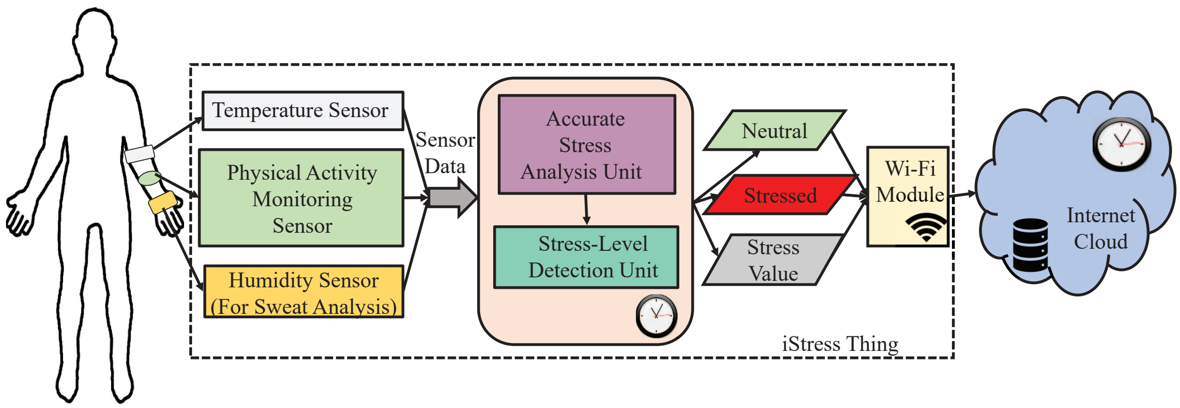

Fig. 2. Proposed Architecture of the iStress System.

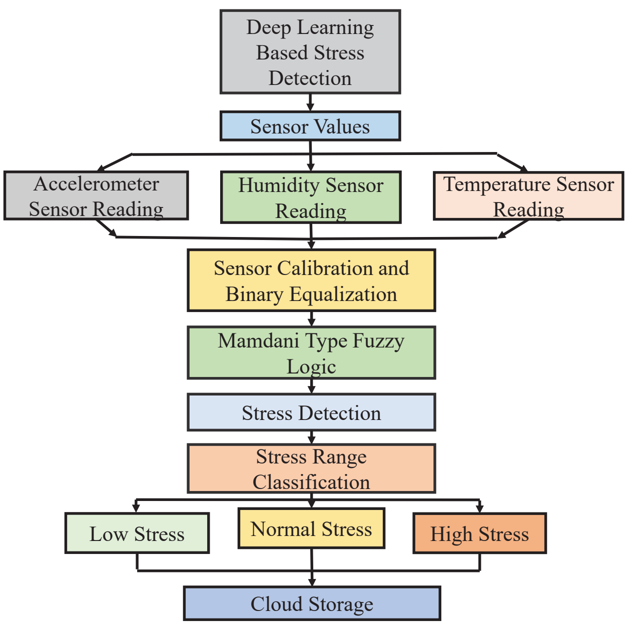

Fig. 3. The Proposed Novel Unified Approach using Fuzzy Logic Stress Level Detection in iStress.

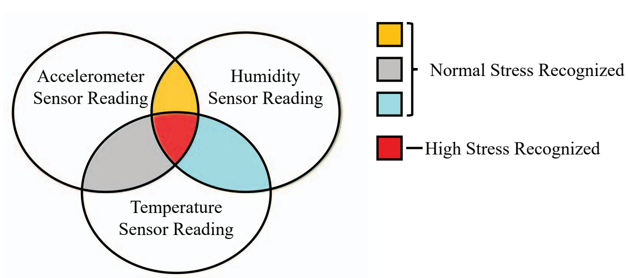

Fig. 4. Conceptual Modeling of Logical Analysis For Stress Detection.

TABLE I
RANGE OF SENSOR VALUES.

Sensor	Low Stress	Normal Stress	High Stress
Accelerometer (steps/min)	0-75	75-100	101-200
Humidity (RH%)	27-65	66-91	91-120
Temperature (°F)	98-100	90-97	80-90

Figure 5 shows the rules which are given inside the Mamdani controller by the user.

2) System-Level Validation: The stress range classified data are being sent to the Internet loud through Wi-Fi where they are stored in a database. In order to connect to the cloud server, the Thingspeak platform used.

B. Consumer Electronics Implementation and Validation

In this section, the logical analysis of Fig. 4 is implemented with hardware. Figure 6 shows the complete experimental setup. An Adafruit Si7021 Temperature and Humidity Sensor along with Arduino/Genuino 101 were used. The Arduino/Genuino 101 has a 6-axis accelerometer and a built-in gyroscope which is used as the accelerometer sensor in this experiment in order to find the step-count of a person, through which the use of external accelerometer sensor to the hardware setup is disabled.

A comparative perspective of our system is given in Table II.

VII. CONCLUSION

A novel machine learning approach for stress detection has been implemented. The consumer electronics implementation of this approach uses temperature, humidity and accelerometer sensors. The detected stress value is then classified to three levels: low, normal and high. The ease of accessing the data off-line is provided by an IoT cloud implementation. Cloud access and verification is via an on-line cloud software provider. The results of the proposed system, iStress show an accuracy of 97% in determining the stress range of a person. Also, the system has been developed with minimum complexity, low power consumption, no need for user interaction and at moderate cost.

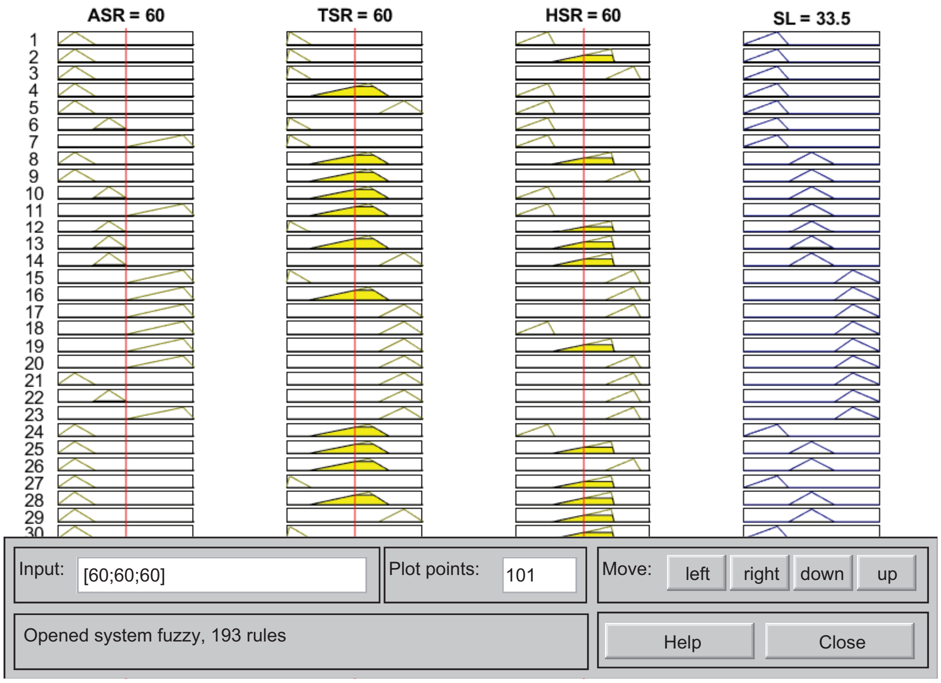

Fig. 5. Grid Partitioned View of Rules in the Fuzzy Logic Controller.

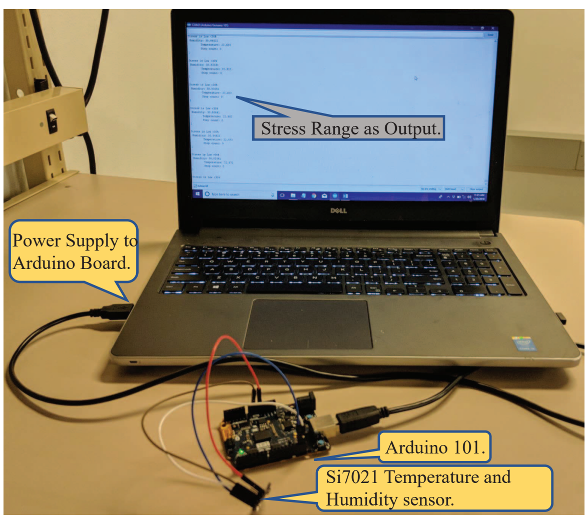

Fig. 6. Experimental Setup for the Proof of Concept.

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TABLE II
COMPARATIVE PERSPECTIVE WITH OTHER STRESS DETECTION SYSTEMS.

Research	Stressors	Sensors/Things	Accuracy %	Cost	System Processing	Energy Consumed	System Complexity
Wijsman, et al. [9]	Puzzels, Calculations, Memory Tasks	ECG, Respiration, ESR	74.5	High	Edge (at the sensors)	Moderate	Moderate
Zhang, et al. [26]	Daily Acivities	Photoplethysmogram	not available	Moderate	Edge (at the sensors)	Moderate	Moderate
Plarre, et al. [27]	Public Speaking, Maths	Skin Temperature, Accelerometer, ECG, GSR, Respiration	90.2	High	Edge (at the sensors)	Moderate	Complex
Sandulescu, et al. [28]	Physical Activity	HR, Humidity, Temperature	85.7	High	Edge (at the sensors)	High	High complexity
Zhai, et al. [29]	Stroop Color Test	Pupil Diameter, Skin Temperature, GSR, Blood Volume Pulse	90.1	High	Edge (at the sensors)	Moderate	Complex
Begum, et al. [30]	Verbal, Math	Finger Temperature	80.0	Moderate	Edge (at the sensors)	Moderate	Moderate
Choi, et al. [10]	Mental Arithmetic, Stroop Color Test	Respiration, GSR, Heart Rate Monitor	83.0	High	Edge (at the sensors)	Moderate	Complex
Akmandor, et al. [31]	Memory Game, Fly Sound, IAPS, Ice Test	ECG, BP, GSR, RESP, BO	95.8	High	Edge (at the sensors)	High	Complex
iStress	Physical Activity	Temperature Senor, Humidity Sensor, Accelerometer Sensor	97	Moderate	Edge (at the sensors)	Low	Less Complex

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