i-lete: An IoT-based physical stress monitoring framework for athletes

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***Abstract*—Wearable devices are ubiquitous and Internet of Things (IoT) devices have made it possible by connecting real-time devices to virtual cloud. There are also a tremendous number of IoT-enabled consumer products for various healthcare applications. Mostly, IoT devices are used for health monitoring systems, though other business and service communities are customizing the IoT technology for greater opportunity and long-term benefit. Wearable health devices have been used for better health monitoring and exchanging more data with the physician to get the guidance of treatment or earlier diagnostic. Health monitoring in athletes is one of the multifaceted applications of wearable IoT devices whereas these devices collect and store data on their performance and progression. This technology can protect athletes by detecting any adverse health problem that occurs during the training period or at the time of the game. In this paper, we investigate the real-time monitoring of physiological parameters of the athlete during game time and performance analysis from the stored data. Continuous health monitoring during game time and off-days will reduce sports-related risks,stress and injuries of an athlete even sometimes it can save them from life risk fatal accidents. This research integrates an IoT-based framework to develop a stress index for athletes that can be used as an indicator for monitoring athlete's health. The proposed framework helps in monitoring the variability of the sensor information for the long-term analysis.**

***Index Terms*—wearable health devices, IoT in sports, sensors, athlete's health monitoring**

I. Introduction

Advances in computation, manufacturing and communication technology bring the notion of the Internet of things (IoT) and IoT-based applications are comprehensively used in smart cities such as smart homes, security, tracking and localization, education and so on [22]. The introduction of IoT in sports is gaining alot of momentum in the sports industry to make a seamless and interactive experience for athletes as well as fans. IoT was introduced in the 1990s when the internet was connected with a toaster to make it remote-controlled [1]. With the advancement of time, IoT technology represents an extensive ecosystem where applications have expanded to health, automation, agriculture, sports. Introduction of IoT technologies in smart sports industry is changing its landscape [2]. At present, integrated circuit (IC) manufacturing companies are producing an abundance of microelectronics, telecommunication devices, data analysis processes and sensors. These help to implement plenty of wearable devices [3] and all of these IoT technologies and devices are employed to monitor health from different perspectives [4]. Sportsmen health monitoring is one of the multifaceted applications of wearable IoT devices [5] whereas these devices collect and store data on their performance and progression. IoT has opened up a plethora of applications for athlete and depth analysis of athlete performance [6]. With the advancement of technology and the IoT revolution, the market of healthcare devices increasing rapidly both in the research and commercial field. In the wearable device market, the amount of revenue was $83.32 billion in 2016 and now, it is predicted to be around $265.4 billion in 2026 [21]. It is important to study user requirements and demand for integrating new devices and these devices are expected to be efficient, reliable and unobtrusive.

There are plenty of sensors that have been used for athletics performance, usually, several sensors are used to acquire an acceptable compression system analysis [8]. All of these sensors can be classified into three categories: motion sensor, physiological sensor and contextual sensors. Motion capture technology is widely used in every kind of sports and a little interval of time can be highly significant because it differentiates an athlete's performance from others. As a result, kinematic analysis using wearable sensors provides real-time feedback and coaches can estimate when the players can recover from injury [9]. In sports applications, a Badminton training system has been developed for next-generation racket sports training [10]. Also, Force-sensitive sensors (FSR) are implemented to increase the accuracy of scoring chances in the soccer game [11]. By this system, it can be visualized the different angles of walking, jogging and the timing of the kicking of a soccer ball.

In this research, we propose an IoT-based framework for measuring both physical and internal stress of sportsmen. This framework will help in recording daily activity, training, fatigue, stress,and mood of the user and create a user profile accordingly. The thematic overview of the proposed i-lete system is given in figure 1.

Studies show that during exercise mental fatigue impairs sport-related performance at an average intensity and not during exercise performed at maximal intensity.The proposed framework will use a smart chest band along with a mobile

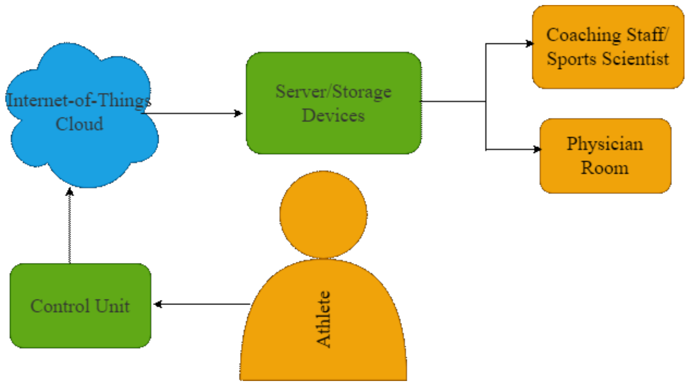


Fig. 1. Thematic overview of the proposed i-lete monitoring framework

application to help in creating a physiological profile for athletes using which the trainers, physicians and coaching staff can monitor the athletes health. Different wearable devices are used to collect data with multiple electronic components which are connected to the mobile or internet . From these devices, all information is collected and stored in the cloud database continuously for future inspections. The proposed framework can be easily integrated as a light weight health monitoring framework for performance analysis in athletes.
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 i-lete framework and smart chest band is described in IV. Some literature on existing research work on health monitoring frameworks is discussed in Section III. An overview of the system-level modeling of the proposed framework is given in V. The implementation of the designed sub-blocks along with simulation results and the corresponding limitations are discussed in VI.

II. Novel Contributions

Physiologic sensors for empirical analysis are the most common types of sensors such as heart rate measuring by using chest belt, blood pressuring monitoring, temperature and heat flux, blood chemistry and breathing frequency monitoring [12]. Similarly, several other types of sensors are used for research work sometimes for commercial purposes. Comfortable, lightweight and easy to wear sensors are the basis of IoT in health monitoring likely Bragg fibers sewn into T-shirts/clothes for respiratory monitoring [13], waistband [14], chest band [15], smartwatch [16], ECG sensor that is embedded into cloth are a very promising form of data collection and storing nowadays [17]. Wearable health monitoring technology incorporates different kinds of sensors which help to reduce alternative analytical instruments and save a lot of time [7]. Scholars/physicians are paying a lot of attention to athlete health and implying different methods to make them fit. IoT into sports has opened a unique era for athletes not only fitness assessment but also performance analysis. The main aim of this paper is to monitor the health of the athlete and obtain substantial health information and analyze the stored data on a scientific basis to improve the quality of the athlete and game. The main contributions of this paper is summarized as follows:

1) A lightweight smart chest band for monitoring daily activity and vital signs in athletes
2) Fatigue analysis using the sensors integrated in the i-lete chest band.
3) User's mood analysis using mobile application.
4) Physiological stress and fatigue profile using a mobile application.

III. Related Prior Research

Traditional health monitoring and data processing consume a lot of time, additionally, it is hard to forecast the required information such as exact fitness level [25]. Physical fitness assessment in sports is one of the popular topics nowadays especially the elite sportsmen always try to fit them to get success in competition. Athletes' physical conditions can be tracked by using smart sensor technology and neural network [28]. G. Manogaran proposed a Bayesian deep learning neural network [29] using edge computing that helps to monitor adults' and kids' continuous activities to predict the health condition. These sensor networks are placed on the human body for continuous data acquisition.

Usually, the fitness assessment of athletes mainly covers physical abilities such as aerobic capacity anaerobic capacity and power, mobility, neuromuscular capacity, speed, change-of-direction and efficiency [30]. Previously, athletes and instructors had to depend on the human-oriented systems. Consequently, the missing vital information, and questionable validity of stored data hindered the post-performance analysis of sportsmen. So, IoT-based smart sensor technologies resolve the difficulties present in the traditional health information collection processes [26], [27] . IoT technologies make data collection, processing and storing easier and digital biomarkers are more objective for a few characteristics such as a real-time nature, real-world applicability and data availability [23], [24]. Sports scientists are hired by sports management to disperse the solid data, which is acquired by wearable sensors and aftermath, these data help to comprehensible for managers, coaches and players. For example, sensing devices and cloud computing in the sport of football for health and performance monitoring reduce the acute injuries of footballers. In recent years, there has been plenty of research on human health monitoring but there is not much for athlete professionals [31]. In this research we aim to address this gap by modeling a stress and fatigue profile for athletes based on the data acquired through the sensors.

IV. Smart Chest-band for Athlete Health Monitoring

Wearable devices are increasing the popularity for monitoring human health and fitness through convenient easy-to-use frameworks [19], [20]. It is very hard to track every sportsman's health condition and performance using traditional equipment. This IoT framework will be helpful to study the user's health and create a physical stress and fatigue profile

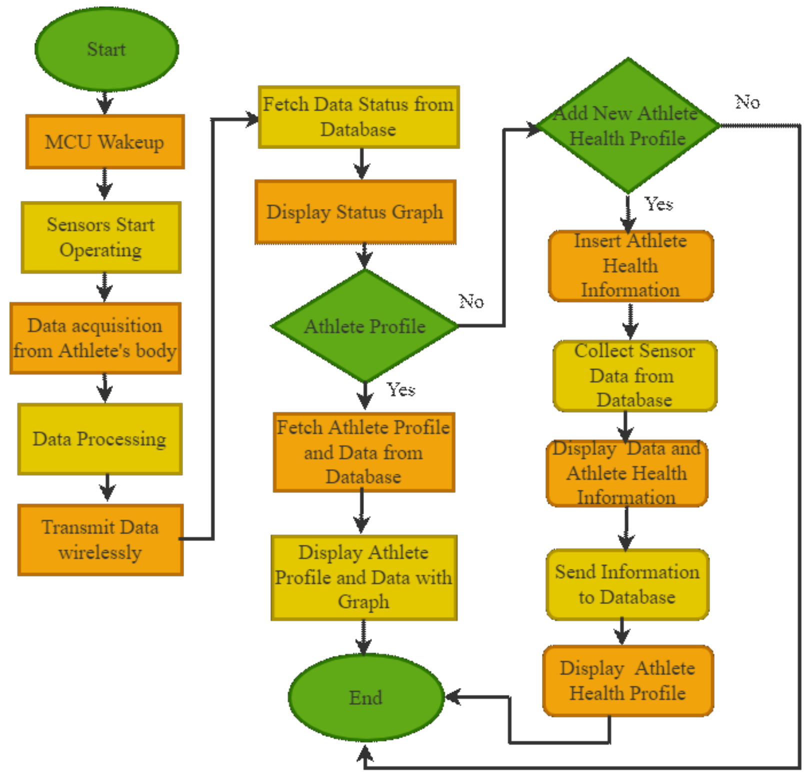


Fig. 2. Flowchart of the proposed i-lete system

for each user. This will help the athletes to maintain a balance between their training schedules and recovery days. The proposed wearable chest-band for health monitoring system includes multiple sensors that can be implemented with textile or adjusted with a band to detect important physiological parameters of the athlete body. The collected data from the sensors will be sent to the data processing unit i.e. a micro-controller board (MCU). With all these health information on the game time or during practice, the coaches and physicians can monitor the athletes health continuously. The chest band corresponds to the central modular design and the control unit maintains the entire data collection/transmission and communication with each unit. Each module is independent that's why it is very convenient to upgrade and maintain the system. When the wireless communication module gets the command, it starts to operate and makes a connection with the wireless network. Consequently, all sensors (ECG sensor, heart rate sensor, and accelerometer sensor) will transmit data to the main control unit. The wireless communication module sends all collected signals to the server. Finally, the cloud server stores and converts the data, making it accessible to the apps and web for a specific purpose.

V. Design Methodology of i-lete Framework

The proposed i-lete framework consists of a smart chest band connected to a mobile application through which the "fatigue index" for the athletes is analyzed. This helps in creating a unique index and profile for each athlete.

A. Modeling the frame using feature

The proposed wearable health monitoring systems for athletes include a different type of sensor that can be adjusted on the surface of the body or can be implemented in any wearable textile clothes that will measure the physiological parameters of the athlete. The data is collected by the sensor and this information is sent to the central cloud where the healthcare professional can look upon the data and take appropriate decision. Table I shows the list of sensors used for acquiring the appropriate health information

TABLE I
List of sensors used for i-lete chest band

Sensor type	Type of Features
Electrocardiogram and Heart rate sensor	Heart rate variability
Accelerometer	Gross body movement

In a wearable health monitoring device, there are two different systems of transmitting data: firstly, the sensors collect the physiological data send to the central node and secondly, transmit the measurement data to the system where the physician/managers can analyze the data. This data transfer is a challenging task because the mobility and comfort of users will be highly restricted if it is a wired data transmission process. Moreover, the short-range data transmission can be used by multiple wired or wireless links.
The sensors collect data from the human skin and send data to the access point via a wireless channel. As presented in the

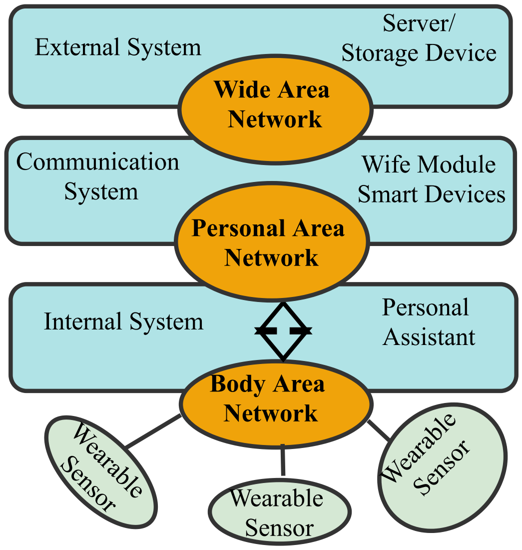


Fig. 3. Communication block diagram of the proposed system

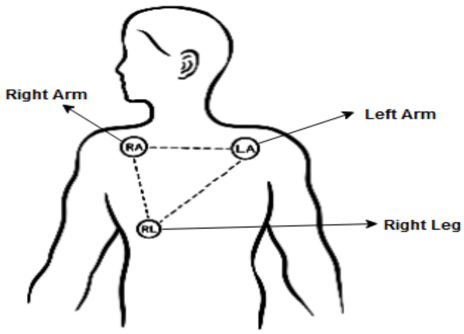
system figure, the overall system mainly includes a) Sensor module b) Controller, and c) Power module. The sensor module is the foundation of the monitoring node, which collects the core information from the user body. All the sensors can be integrated as a chest band with a microprocessor and a communication unit that can connect wirelessly. So, a powerful CPU with low power consumption and a low power communication system will be used for an interoperable monitoring unit.

B. Communication Block Diagram

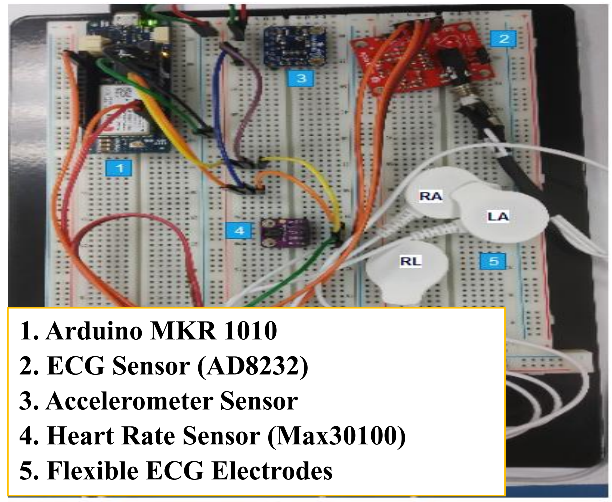
To implement the IoT application for athlete health monitoring, a service-oriented architecture for athletes is proposed. Figure 3 provides the sample overview of the data transmission system. This entire topology is divided into three parts: (a) data acquisition system (b) personal assistant and (c) server. Each sensor transmits data to the personal assistant, and it contacts the appropriate internet server after selecting network access. The assistant is the most important component in the system because the operator gets necessary information from the assistant and observes thoroughly. There are three types of components are connected in this system: Body-area network (BAN), Personal area network (PAN), and Wide-area network (WAN) as shown in the communication block diagram in figure 3 . The data acquisition unit can transmit and receive data via the gateway. To implement the IoT system for athlete health monitoring, there are several characteristics the system needs to accommodate. This system consists mainly of three layers: Perception Layer which the body area network sensors are connected, and these sensors collect the physiological parameter from the body of the athlete. The sensors operate with a gateway to receive and send the signal to the control unit. The system needs to exchange information with the body sensors in terms of getting accurate results. The Network Layer helps to transmit a packet of data with a different network. Different technology can be used for the base station and this station relates to a domain via a wired connection. Finally, The Application Layer analyses all data that come from the sensor and provide accurate feedback to the managers/coaches. Also, it can store data for further observation and analysis.

VI. Implementation and Discussion

To investigate the health of the athlete, a few physiological parameters can be measured to get a better understanding of the health status and create a stress profile. We have used an ECG sensor, Heart rate measuring sensor, and Accelerometer sensor to observe the health condition of the athlete. Understanding the pattern of complex bio-signals is very important because it contributes to better human health analysis and we can identify if any anomalies occur. The heart behavior of athletes during the game can be monitored with a better quality of ECG signal. For this research, the AD8232 ECG sensor, MMA8451 Accelerometer sensor, and MAX30100 Heart Rate Sensor are used for the health monitoring of the athlete.The data acquired from these sensors are used for creating heatlh profile for the athletes. With the help of ECG sensor, accurate ECG signals can be detected, since the frequency range of the ECG signal is between .5 Hz to 100 Hz. Accordingly, the accelerometer sensor measure movement with higher sampling rates. Moreover, the short-range data transmission can be used by multiple wired or wireless links. The hardware part of this project consists of the Arduino MKR 1010 unit which is based on SAMD21 Cortex-MO low power consumption microcontroller unit including integrated sensors. Figure 4 shows the experimental set up of the proposed i-lete framework. As electrocardiogram (ECG) signals are the most important and widely used parameter, this wearable device will collect data continuously to monitor health conditions. The ECG waveforms provide information on the cardiac electrical signal. The athletes undergo different physical and mental conditions changes during the game. So, it is inevitable to detect the sudden rise or fall of the heart rate of an athlete. An ECG signal helps to discern where the heartbeats are too quick, too slow, or irregular. To measure this type of parameter, we have used skin electrodes that can be adjusted with a chest band. Each of the signals represents the alteration of electrical potential in the heart. The purpose of using ECG signal is to continuous causality monitoring and it can be done by setting different triggers for each person. As a result, any risk injuries, or collapses during the game can be analyzed or resolved. Figure 5 represents a sample heart rate that is collected from a volunteer for a six-minute period. The setup of this ECG sensor consists of electrodes that are placed on the chest and variability of this can be done but it needs more flexible devices. However, these ECG sensors record the activity generated by the athlete's heart muscle depolarization (a negative electric charge) that propagates as pulsating electrical waves towards the skin. Though the amount of electricity is very small, this integrated sensor attached to the skin can be attached to the chest band framework.



(a)



(b)

Fig. 4. Design setup for the proposed i-lete framework a. Placement of the ECG sensors; b. Proof-of-concept of the proposed i-lete framework chest band

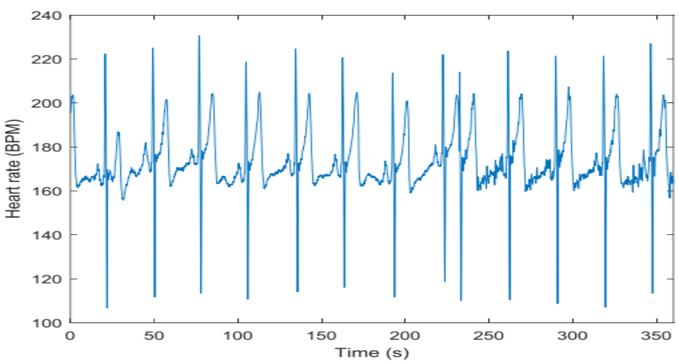


Fig. 5. Heart rate monitoring using the prototype for six-minute period

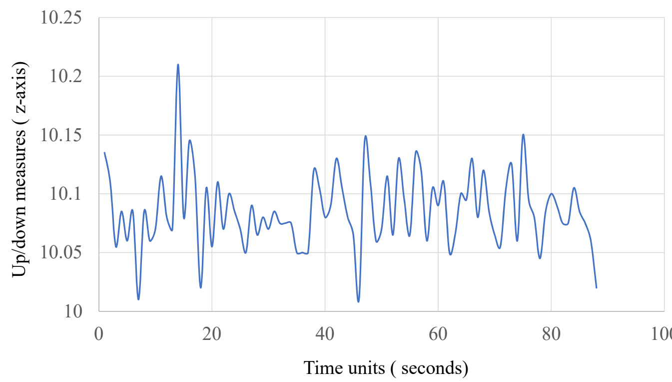


Fig. 6. Accelerometer measurement in i-lete framework

Figure 6 illustrates the output from an accelerometer sensor where a sample result has been presented to show how this system will extract data effectively from the athlete's body. This sensor can measure the force and movement, rotation, and body orientation of the athlete. Since the data is collected including warm-up time, the sensor can detect changes in force or direction of force which indicates injury or fatigue. As a result, the coaches and sports scientists can compare the health condition of athletes. The presented graph describes the output of the sensor and from this, we can quantify the athlete readiness and fatigue in the field. For athlete's health monitoring, it is very essential to monitor the body movement, especially it is widely used in actigraphy, monitoring the activity cycle, and human rest. This chest band will record the mobility of every athlete and provide insightful information about the current health condition of the athlete. The accelerometer sensor can provide guidance and feedback on the athlete's health and able to generate warnings based on the person's physiological conditions. Through this wearable device, we can know the movement of the sportsmen that directly allows accessing the physiological signals, body kinematics, and fatigue level during the exercise or game time.

VII. Conclusion

Wearable and IoT devices have opened a new era for athlete health monitoring. This proposed IoT-based monitoring framework uses wearable sensors to obtain the physiological information of the athletes and the collected data from the sensors could be used for further performance analysis. The main objective of this research is to investigate continuous health monitoring of athletes to reduce the incidence, injuries and sported related fatalities and improve the efficiency of the athletes. Using this device, the coaches, physicians and managers can get information about physiologic and movement parameters. Also, they can plan an efficient sports-specific training program for performance optimization and reduce potential accidents. As it will monitor both the external and internal workload of the person, its application will be versatile. Future research involves designing a user interface that can be an one-stop solution to monitor nutrition and provide proper medical attention that can highly improve the overall success of an athlete.Further the stress index will be used for maintaining overall health of the athletes.

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