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Modernized IoT-based Intelligent Helmet System to Monitor and Protect Sportsman

Nahlah M. Shatnawi[1], Ra'ed M. Al-Khatib[2] and Khalid M.O. Nahar[3]

[1,2,3]*Department of Computer Sciences, Yarmouk University, Irbid-21163, Jordan*

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Abstract:The applications of the Internet of Things (IoT) model and their ability to aggregate real-time data from wireless sensors shed the light to develop new IoT-based technological systems to monitor and protect the health of sportsmen. In this paper, a new modernized IoT-based approach is proposed for monitoring the head of the sportsman using a concussion sensor (3-Axis Accelerometer Module GY-61) mounted on the top of the helmet to detect any sudden and improper hits. Furthermore, another sensor for measuring the temperature is also added to the helmet in order to monitor the temperature of sportsman. Those sensors are worked together for continuously monitoring any abnormal hits, especially on the head part of the human body. When an abnormal hit or any concussion occurs, the human body responds by increasing the temperature due to the brain movement inside the skull. Consequently, the proposed system will directly alert medical staff about any abnormal and dangerous hit by sending sensor readings. An experimental process is conducted to test and evaluate the proposed system using a real case study applied to the boxing helmet in a realistic style during the match. Results showed that the proposed helmet system outperforms similar state-of-the-art systems by the mean of accuracy and response time. The accuracy reaches 96% with different types of matches.

Keywords: Arduino, Biometric Data, Boxer Helmet, Concussion and Temperature sensors, IoT, Sportsman Health, Accelerometer.

1. Introduction

Internet of Things (IoT) stands for the physical objects (things) that can be connected and interacted remotely with the Internet via wireless sensors. IoT was firstly coined in [1]. The main goal of IoT is to interrelate and connect computing devices, machines, objects, animals, or people through the Internet [2]. This interrelation is done by providing things with unique identifiers, which gives the ability to transfer data over the network without requiring any human/computer interaction [3]. The applications of IoT-based connectivity systems are sustained at "any-time" from "any-place" for "any-one"; things may be a person with a heart monitor implant, an animal farm with a bio-chip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low, or any other natural or man-made object that can be assigned the IP address and provided with the ability to transfer data over the network [4].

Monitoring the health of the patients is also carried out with the assisting of IoT-based technology such as; the use of the Wireless Body Area Network (WBAN) for out-of-hospital patients [5], [6]. Furthermore, IoT-based technological systems are developed to efficiently monitor the health of athletes and sportsmen. For example, there is an IoT-based application for monitoring the sportsman/woman during indoor practice sessions [7]. Another example of IoT-based health system is a system called "Smart Clothing", which provides a sustainable medical emergency for monitoring the body gesture of sportsman in training session [8], [9]. From the literature, found many IoT-based systems have been proposed for monitoring health services using different kinds of wearable computing sensors [10], [11], [12]. However, there is still a gap in developing an accurate real-time IoT-based system to monitor and protect the sportsman during matches.

In this research study, a new modernized IoT-based system is proposed to continuously monitor any abnormal hits to the head of the sportsman. The proposed system has utilized the power of a concussion sensor (3-Axis Accelerometer Module Gy-61) combined with the temperature sensor to directly monitor the status of sportsmen on both sides; the stability of the head and the temperature of the athletes' body. For experimental tests, the proposed system is implemented in the helmet of a boxer player as a real case study in three different athletes (i.e. Boxing, Kick boxing, and Karate). The output results of proposed system will directly alert the medical staff to any sudden or improper hits incurred by the player, and may be harmful and dangerous

E-mail address: nahlah.s@yu.edu.jo, raed.m.alkhatib@yu.edu.jo, khalids@yu.edu.jo

to his/her health. Consequently, the proposed system will contribute to protecting the boxer or the athletes' health.

The rest of this paper is organized as follows: The background and related works are introduced in Section 2. In Section 3, the proposed method for developing new smart helmet based on IoT technology to monitor and protect the sportsman is fully described. The obtained experimental results are discussed in Section 4. Finally, Section 5 concludes the works and presents some future directions.

2. Background and Related Works

There are many effective IoT-based techniques that have been proposed in the literature to use wearable devices, in order to build and develop modern systems to monitor or detect the status of athletes during different sports activities. Such monitoring smart wearable systems become more popular due to their simplicity, efficiency, and their efficient applications via smartphones [13]. The main motivation is to propose a new IoT-based intelligent helmet method that can be designed for suitable monitoring sportsman's health in taekwondo or any kind of match. Further, it can be used with athletes that need helmets like cricket, hockey, snowboarders, bobsleigh, road cycling, mountain quad bike, college football, and other adventure athletes. There are many IoT-based systems presented in the markets that are produced to support only tracking measurements (calories burnt, heart rate, swing, and tennis stroke), as wearable devices [14], [15], [16], [17].

The importance and the benefits of monitoring the athletes in sport-activities are fully discussed in the subsequent sections. This is illustrated as the main background before covering the IoT-based technologies that have been introduced in the literature for supporting and protecting the health of athletes. After that, the architecture and hardware details are presented for constructing the design of the proposed IoT-based system in the last part.

A. Benefits of Athletes' Monitoring

The athletes during sport-activities usually give subjective information when asking them about their feelings like tiredness or stress. The collected subjective information is not always objective, because athletes want to show themselves in the best ability to accomplish the sport-activities and training sessions. Therefore, getting objective measurements for their feelings using real-time sensors is vital and accurately measuring their physical changes and bio-information during athletics [18], [19].

Consequently, the process of monitoring athletes' health indicators via using IoT-based technologies will ensure the best performance of athletes, and it will assist in identifying the potential hits or any sudden injuries [20]. Therefore, the monitoring of athletes' health is more effective to plan for safe athletics health. Furthermore, determining the timing of symptoms on set correlates of diagnosed concussion without any delay, is essential to predict the most dangerous hits or any intermediate risks on the head [21], [22]. Thus, IoT-based instrumented helmets are put on athletes to directly measure the acute and most dangerous hits, or to diagnose any sudden concussion or injuries of the head.

B. IoT-based Technologies for Athletes

In this section, the state-of-the-art methods and functions that have been introduced in the literature presented. Moreover, all studied methods and functions are based on IoT technologies that are used for monitoring and protecting the sportsman's health. Nowadtheys, monitoring and protecting the athletes' health is demanding and obligatory in athletics laws and regulations. However, most existing wearable and IoT-based devices focus on data collection rather than monitoring and analyzing the hits. Only a few latest IoT-based systems were integrated within the helmets of athletes to sense the real-time data for sudden injuries.

Several studies use IoT technologies for monitoring the performance of sportsmen/women, which are mainly based on data collection. The main aim of such studies was to come up with better modified monitoring and protecting systems for athletes during their daily activities.

In [8], the "Smart Clothing" system was designed and introduced to obtain sustainable health monitoring using a real-time tactile application. The system is based on mobile and cloud platforms. One of the "Smart Clothing" system usage was to monitor the golf trainers and players for improving their professional performance.

In [23], the authors developed a smart application based on Wireless Sensor Networks (WSNs) and IoT scenarios for data collection. A mobile GUI application was implemented to improve the conditions of sportsmen/women through their exercises in the gymnasium.

The researcher in [24], presented a ZigBee-based system that was used with intelligent helmets to make a real-time safety system for monitoring the temperature, humidity, and methane-gas in the mine area. The ZigBee-based system communicates with miners using voice alerts to protect them from any dangers.

3. Proposed IOT-based System

In this section, the overview of the proposed system is discussed. Then the details of the IoT-based sensing system are fully explained. Finally, the interface and communication through developed applications and online databases are discussed in detail.

A. System overview

Does monitoring athletes help? Of course, monitoring helpsbetter-modifiedn keep track of how the athlete is reacting in training or during the match, how they are sleeping, how they are eating, and what their mood or stress levels are. Then, the coach can make decisions based on that collected information. The key of monitoring is being able to identify potential difficulties at the earliest possible

stage and to take actions to help optimize preparing and training, and in turn, ensure the best possible performance in competition. Monitoring also assists in identifying such potential problems like injury and illness. Each of these factors can hamper an athlete's ability to train consistently. If they can avoid missing training sessions, they will be prepared better to achieve success and win in the match.

Figure 1 shows the structure of the proposed IoT-based intelligent helmet system to monitor and protect sportsmen during training or competition matches. The proposed system measures body temperature and concussion on the head caused by a competitor during training or match. The readings from sensor are sent to the Arduino microcontroller for further processing and calculation.

Figure 1. General Overview of proposed IoT-based intelligent helmet to monitor and protect sportsman

The main focus is on detecting the hits on the head of the athlete in some combat sports such as boxing, Kick Boxing, taekwondo, and karate; because it's the most effective place to claim more points. The player receives shocks when he receives a strong hit on his head which may lead to internal problems without knowing the real-time circumstance because the body starts to secrete hormones after a while of the hit. This system is used to automatically detect the strength of the hits on the head, which has the helmet provided with the concussion sensor and temperature sensor. In this system, the player situation is measured by those sensors that send information through Wi-Fi to a web page connected with sensors continuously. If the strength of the hit and/or temperature exceeds over threshold value limit, this will lead the proposed system to warn the medical staff to make the diagnosis and make a time-out if the player reaches a dangerous situation; to take medical care of the injured player.

The design of the proposed system is feasible and can be improved further by adding more sensors to measure diverse health parameters. Different hardware pieces are explained with full details in the subsequent sections.

B. *Details of sensing system*

The proposed system consists of two sensing units a temperature sensor and a concussion sensor. Figure 2 shows the main components of the system.The temperature measuring device used is the LM35 temperature sensor; it does not need to be reset every time as it gets in some sensors. The range of measured temperatures ranges from 50°C to 150°C. In this system, temperature values between 30°C to 41°C are used.

Figure 2. Main components of the proposed system based on IoT technology

One of the most common inertial sensors is the concussion (3-Axis Accelerometer Module Gy-61), which is a dynamic sensor capable of a wide range of senses (-3g to 3g). Accelerometers are available to measure the acceleration in one, two, or three orthogonal axes. They are typically used in one of three modes: i) as an inertial measurement of velocity and position; ii) as a sensor for inclining, tilt, or orientation in 2 or 3 dimensions; iii) or as used in this proposed system as a vibration or impact (shock) sensor. The Accelerometer sensor measures hits from three angles as analog measurements that are mathematically explained in the following equation:

$$x = AnalogRead(0);$$
$$y = AnalogRead(1);$$
$$z = AnalogRead(2);$$
$$Magnitude = sqrt(sq(x) + sq(y) + sq(z))(1),$$

where x, y, and z are the three measured dimensions with values ranging between (-3000 and 3000). The sq refers to calculating the square of each dimension, and the $sqrt()$ is the square root for the total, which is computed to measure the real hit strength (magnitude). This *Magnitude* value is classified into three levels low, medium, and high; to determine if the hit can cause any problem or internal injury to the player.

C. *Interfacing and communication*

A microcontroller is used in the helmet, which is the Arduino-Nano USB Microcontroller v3. This microcontroller is programmed to analyze and convert signals from different sensors to digital voltages, and for communication. The data read by the sensors is collected by the Arduino microcontroller. Here, a newly developed algorithm executes in the background to convert the sensed values to temperature in Celsius, and to calculate the concussion value of the athletes. All the collected data are processed by Arduino-Nano, and then sent by ESP8266 Wi-Fi enabled system on chip (SOC) module, which was developed by Espressif system. It is mostly used for the development of IoT embedded applications.

The web page is developed and used in this system; due to its capability of showing the received values on the Smartphone. The magnitude values computed by equation 1, are compared and classified based on the hit strength and temperature to monitor the athletes' situation throughout the training session or match. In casrangingedical distress of the athlete, an alert message is automatically sent to the coach and medical staff. However, the limitation is that the mobile must be internet-enabled over Wi-Fi or mobile data for the app to transfer these details.

4. Hardware Architectural Design and Implementation

The required hardware includes (sensors, wires, batteries, USB cable, regulator, broadband, and microcontroller) prepared. Figure 3 shows the main hardware components. The software built using different programming languages includes C++, Java script, and PHP. For database management MYSQL server program used.

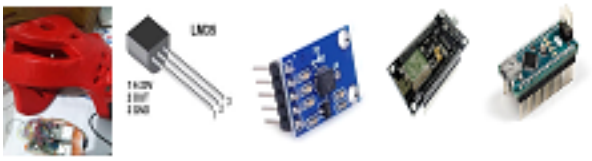

Figure 3. Helmet and the main components include: Temperature sensor, concussion sensor (3-Axis Accelerometer Module Gy-61), ESP8266 Wi-Fi Module, and Arduino-Nano microcontroller

The IoT-based model is implemented using a web page. Also, the wireless temperature, heart rate, and concussion sensors are installed on Arduino controller for monitoring, training, and testing purposes.

The proposed IoT-based system is installed on two computers. The first one acts as the main server for the system. The second computer is used to collect the measurements from the sensors that have been installed on the top of the helmet. After that, the sensors are implemented to be embedded in the helmet, and installing the equipment in a base station, which is located in the second computer (for details of installation see Figure 2). The sensors are worked together for continuously monitoring any abnormal hits on the head part of the human body.

5. Prototype and Experimental Results

The system prototype of the proposed system includes a microcontroller called Arduino-Nano 3.0 version with a mini-breadboard 400 points flat panel; used as a base for electronic components connection. Also, Arduino-Nano is used to construct electronic circuits and prototype electronic devices. Arduino-Nano doesn't require welding and reusable, which makes it very easy to use and to build many temporary models, in order to check the circuit design. ESP8266 Wi-Fi Module enabled system on chip (SOC) module is also implemented and developed by Espressif system. It is mostly used for the development of IoT-embedded applications. The sensor hub contains LM35 Temperature Sensors, and a 3-axis accelerometer (GY-61) with signal voltage outputs.

All used sensors are worked together for continuously monitoring and detecting any abnormal hits on the head part of the human body. When an abnormal and high concussion occurs, the human body responds by increasing the temperature due to the brain movement inside the skull. Consequently, the proposed IoT-based system directly alerts medical staff about such abnormal and dangerous hits by sending the readings from the sensors to the staff. An experimental process is conducted to test and evaluate the proposed system using a real case study that is applied on the boxing helmet in a realistic style during three different matches. The obtained results showed that the proposed IoT-based helmet system outperforms similar state-of-the-art systems with respect to accuracy and response time.

Figure 4 shows the hits reading signal received from the sensor, the consecutive hits form a pulse wave, where each pulse represents a hit. In Figure 4, the wave tells us that all hits are within the range of normality. The pulses represent the magnitude based on equation 1 within the match time.

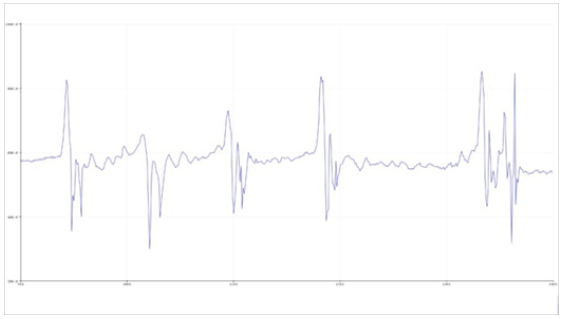

Figure 4. Hits of varying strength, x axis time in millisecond, y axis magnitude

In Figure 5, three types of hits are appeared in the graph, the low and medium hits still in the normal zone, while a pulse with a very high altitude implies of a strong hit. The hits are considered low if magnitude values between (200,400), medium if values are between (400,800), and high values more than 800. The proposed system will directly alert the medical staff if frequent strong pulses appeared, and high-temperature values are detected (more than 38.5°C).

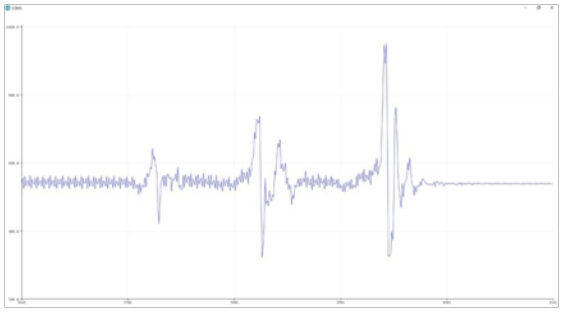

Figure 5. Three types of hits: low, medium, and strong; x axis time in millisecond, y axis magnitude

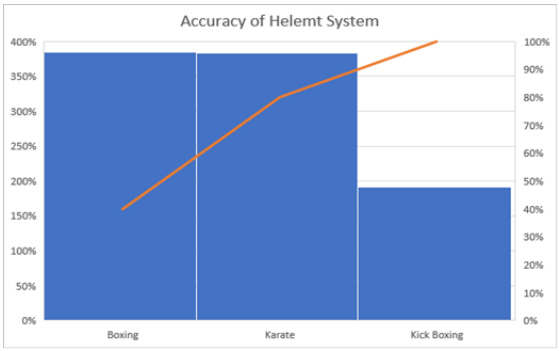

Figure 6. A pictorial view of the experimental results

In cooperation with the sports college at Yarmouk University, the results of about 10 matches from different types of sports were recorded. An expert from the sports college was hired to count the hits on the helmet and determine its level of danger. The system also records the number of times that the helmet of the proposed system alerts the monitoring staff. Table I shows the results of those matches with the average accuracy.

TABLE I. Recordings Of 10 Matches for Different Types Of Athletes

Type	No. Hits	Expert Opinion	Helmet Alert	No. Incorr. Alerts	Accur.
Boxing	50	20	25	5	95%
Boxing	70	35	38	3	97%
Kick Boxing	55	28	26	2	98%
Karate	25	18	20	2	98%
Boxing	80	30	25	5	95%
Karate	50	20	25	5	95%
Karate	35	18	24	6	94%
Boxing	75	25	28	2	98%
Kick Boxing	15	15	21	6	94%
Karate	28	20	24	4	96%
			Average of	Accuracy	96%

A pictorial view of the previous results is depicted in Figure 6, the average accuracy rate reaches 96%, and some games show good results compared to the other games.

6. Conclusion and Future Work

In this research, a new modernized IoT-based approach is developed for monitoring the head of a sportsman using a concussion sensor mounted on the top of a helmet for detecting any sudden or any improper hits. Applied experiments have been performed using the developed IoT-based helmet. The proposed IoT-based helmet system outperforms similar state-of-the-art systems by the mean of accuracy and response time. Even with the difficulties of being sometimes outdoors, the experimental tests show a solid response from the proposed IoT-based system. Future plans include building and creating more smart systems using IoT technology. These smart systems can be deployed to protect, help, and make life easier for people in different areas.

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Nahlah M. Shatnawi Assistant Professor in computer science department, Yarmouk University. Mainly work in Artificial Intelligence.

Ra'ed M. Al-Khatib is an Associate Professor in the Department of Computer Sciences, Faculty of Information Technology and Computer Sciences, Yarmouk University. He has a PhD in Computer Science from Universiti Sains Malaysia (USM), Malaysia. His research interests include: Artificial Intelligence, Machine Learning, Natural Language Processing (NLP), Speech Processing, Text-to-speech (TTS), Internet-of-Things (IoT), and Wireless Sensor Networks (WSN) domains.

Khalid M.O. Nahar Associate Professor in the Department of Computer Sciences-Faculty of IT, Yarmouk University. He has a PhD in Computer Science and Engineering from King Fahd University of Petroleum and Minerals (KFUPM), KSA. His research interests include: Speech Processing, NLP, AI, IoT, and ML.