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A Smart Real-time IoT-based System for Monitoring Health of Athletes

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Abstract: Athletes encounter different types of hits, which sometimes could be strong or light hits. Heavy or strong hits on some parts of an athlete's body such as the chest or lungs may be harmful and cause severe damage to the human body. In some cases, the heavy hits may cause heart failure or a serious lung rupture. In the athlete's healthcare domain, there are potential trails efforts based on Internet-of-Thing (IoT) technology; however, building a comprehensive and efficient system is still a demanding concern. In this paper, we present a new comprehensive real-time platform for monitoring athletes during Mixed Martial Arts (MMA). The proposed real-time monitoring platform is called the IoT-Sports Health system, which particularly fuses based on IoT devices with in-sport healthcare services. Therefore, our proposed system is integrated, designed, and implemented to monitor and measure the athlete's body temperature, strike force, and the number of strikes that the athlete has been received from the opponent. Several real field trials and many experiments proved the feasibility of our proposed IoT-Sport health system, which directly and automatically plays a significant role in chest guarding against heavy and strong strikes. Furthermore, our proposed real-time monitoring system can be easily deployed to monitor aging people that suffering from chronic diseases in-home. In conclusion, experimental tests are performed to evaluate the proposed IoT-Sports Health system by applying a real case on three different matches. The obtained results proved that our proposed IoT-Sports Health system outperforms similar systems with respect to the accuracy, and regarding to the response time.

Keywords: Internet-of-Things (IoT), Real-Time system, Mixed Martial Arts (MMA), Athletes' health, Wireless sensors, Arduino, chest hits

1. Introduction

The health of sportspeople in athletics has recently become a demanding issue. Several types of interesting sports including karate, heavyweight boxing, kickboxing, attract many people around the world [1], [2], [3]. Some kinds of these sports like teaching Mixed Martial Arts (MMA) and boxing can be very dangerous to the health of the people involved. Therefore, making these kinds of sports safe will positively impact athlete's health and increase the interest in such sports [4]. Making these types of sports safe could also be achieved by instantaneously monitoring the effect of the fight on the persons involved such as kick force or strong punch, athlete heartbeat rates, number of kicks or hits that an athlete received, and the athlete's body temperature.

Since Internet-of-Things (IoT) is an integrated network environment that connects several devices to be used over the Internet that may include PCs, sensors, monitors, ... etc., we used it in building our smart real-time system [5]. Many previous smart systems have been developed based on IoT like smart helmets, smart houses, smart irrigation systems, smart biomedical systems, and even smart cars [6], [7]. However, building a comprehensive and efficient system for monitoring health of athletes is still a demanding issue. Based on this fact, we are motivated to build our smart system. Therefore, the advantages of this research study are to mainly design a new chest guarded IoT-based system in order to monitor the body-temperature, the number of athlete hits, and the strength of each hit.

Our smart IoT-Sport Health system is primarily deployed based on MMA teaching sport, contains eight main force sensors that are used for measuring the force of the kicks, and another second set of sensors to monitor the body temperature. Our smart system used the Arduino platform. Arduino is an electronic board used for IoT systems, which is usually for connecting sensors together, and it comes with a programming platform for coding [8]. Information gathered by the installed sensors is broadcasted to mobile applications for analysis and decision-making.

Consequently, the main contribution of this research is to develop a new smart health monitoring system for athletes called "IoT-Sport Health system", which is based on the Arduino platform embedded in the jacket of sport

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people. Therefore, the objective of the proposed system is to combine an IoT system with sensors in order to monitor the biomaterials of the body with Smartphone applications to take the data from the sensors on the chest guard. The final output data will be illustrated as analyzed information on the smartphone screens. Also, the application of proposed system can be easily worked on both Android and iOS platforms.

The remainder of this paper is organized as follows. Section 2 introduces the preliminaries and related works. Section 3 provides the framework of the proposed IoT-based system, and then introduces the proposed system for monitoring the health performance of athletes during MMA. Section 4 evaluates the efficiency of the proposed system from various features via real-time athletes' experiments. Section 5 concludes the work and suggests some directions for further research.

2. Preliminaries

The health of sportsmen and in-home patients' healthcare has recently become a very important issue [9], [10]. There are various trials to move the manual medical checking and traditional healthcare monitoring services, to be managed by remote real-time treatment systems based on IoT trends [11], [12], [13]. Firstly, athletes can get more efficient with the real-time healthcare, by developing a comprehensive IoT-based system [14], [15]. Secondly, remote monitoring of sports training from the professional medical team could seamlessly reduce the financial burden of the activity, and then decrease the proportion of human intervention to stop the athletics during the sports/training participation [16]. IoT-based services for the healthcare of sportsmen and athletes will significantly reduce the cost of medical monitoring system, and efficiently manage the monitoring process even in training sessions [17]. Meanwhile, IoT-based technologies consider harnessing the medical care of monitoring sports systems with a comfortable environment by utilizing the power of information and communication technology (ICT) [18], [19], [20]. Consequently, it is crucial in the coming near future to build more practical health systems.

To monitor the physical status of athlete's, and to keep update their health status during athletics and sports training, the following tasks should be directly controlled: 1) Real-time intelligent monitoring and vital analyzing to directly detect the heavy hits and the number of dangerous hits. 2) Inspecting whether the athlete's body received serious hits from the opponent, and the proposed smart system should directly measure that the athletes follow the standard training regulations and obey the rules of playing sports [21]. However, with the wide expanse of MMA and sports training sessions, there are vast necessities and big challenges to introduce efficient systems for athlete's healthcare.

Many research studies in the literature proved that a high proportion rate of sportspeople does not adhere to the regulations and rules, which leads to not 'fair play', occur in sports activities [22]. These behaviors of poor adherence to the sport rules are considered a major issue and moral problem that may cause bad health, severe injuries, and dangerous hits among players [23]. Therefore, there is a high demand for using the latest trends of technology to improve the facilities of controlling the adherence of players with rules, and automatically monitoring their healthcare services. Using these smart latest technological systems will cover this research problem of controlling the sportspeople in order to keep them adhere to the regulations and rules.

Internet-of-Things (IoT) is a new revolution of ICT, which involves connecting objects and devices with the universe network via Internet services by utilizing the power of sensors, actuators, or any other wireless devices [24]. One of the main advantages of IoT is connecting several smart objects during people's daily lives, which is the main target for the IoT-based systems in the next-generation (i.e. 5G wireless Networks) [25], [26]. This can substantially bring more benefits by improving the efficiency and performance of various modern industries like healthcare, home appliances, heavy equipment, logistics, airlines, and manufacturing [27]. Therefore, several companies started inviting huge investments to use IoT technologies in their products, which open the door for exploring modern innovations and new business opportunities. In the literature, many research systems and IoT-based applications have been introduced in the field of healthcare and the protection of sportspeople [26]. However, building a prominent system for monitoring athletes' health is still the main challenge, which makes a potential motivation to propose this research work.

3. Proposed System

In this section, the details of our proposed IoT-Sports Health system are thoroughly discussed. Then, we give an overview of the developed IoT-based system, by considering the important features in MMA sport. Figure 1 illustrates the main scenario with general concept of our proposed IoT-Sports Health system, where some parts of Figure 1 are adapted from [28]. An intelligent health pack (iHealthPack) is developed to serve as the main healthcare gateway, has IoT devices (e.g., force sensors, blood pressure sensor, heart rate gauge, and temperature sensor). This iHealthPack is connected to the Control-Team via heterogeneous network, which is integrated with several existing wireless nodes. All sensors and devices in this developed iHealthPack can automatically detect and directly transmit the athletes' biosignals to the base station. In real-time, the collected data is transmitted via a cloud network to the control and medical teams that are monitoring the sports activity for direct analysis and in order to provide a response of decisions.

The key contribution of the proposed system is that it can easily expand the scope and handling of typical healthcare information systems (HIS). It can be remotely re-implementing from a hospital location to aging patients

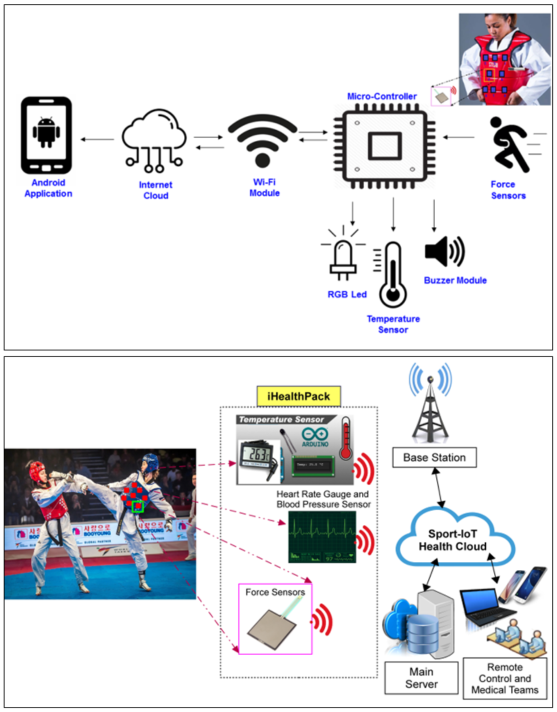


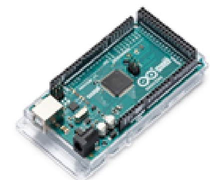
Figure 1. General workflow of proposed system, some parts from [28]

at home [10], [29]. This will make it fully compatible to comprehend and incorporate with HIS systems. Consequently, this paper explains the integration of developing several smart sensors including the iHealthPack that has all demanded biomedical devices to detect the bio-information of athletes at the body level without any direct intervention from the medical team during the sports match or training session. This will use to achieve the biodata, which can be automatically sent via IoT-health Cloud network to be analyzed in real-time at the level of control staff and medical team [30], [13]. Consequently, the proposed system is designed in a feasible way, which can be further extended by implementing extra sensors in order to measure or detect any more specific health parameters. A detailed explanation of the hardware implementation of the devices used in the proposed system is given in the following subsections.

A. Architecture & sensing design

This subsection discusses the required components and sensors that are used in the proposed system and embedded in the sport-jacket. Two different types of components for detecting and sensing are primarily implemented in our proposed IoT-based system. These components include: eight force sensors, and temperature sensor. In addition to these sensors, there are wires, USB cables, microcontroller, batteries, and regulators, which are required as extra hardware components. These extra hardware components are the primary elements to perform the sensing process. Table I shows the main devices and components used in designing the proposed IoT-based system.

TABLE I. Sport-jacket and main sensors and components

Component or Sensor name	**Shape or hardware design**
Sport-jacket	
Arduino Mega	
ESP8266 Node MCU WiFi	
Force Sensor	
Temperature Sensor	

The software developments of the proposed system are implemented in JavaScript, C++, and PHP programming languages. The database management is deployed using MYSQL server programming tools. The website of the proposed model is built with a web page implantation. For detecting and training purposes, the different types of sensors are installed and integrated within Arduino mega controller and Wi-Fi ESP8266 module in the proposed system. Finally, the end users of the proposed system are integrated into two sides of computers (server-side and client-monitoring-side). Firstly, the main computer is primarily installed as the main server-side, to directly analyze the

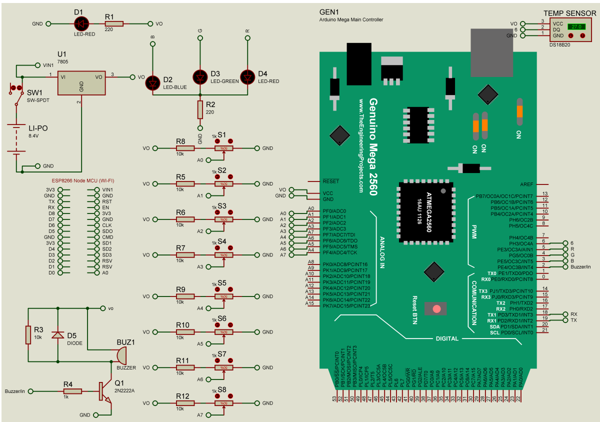


Figure 2. Architectural design of proposed system

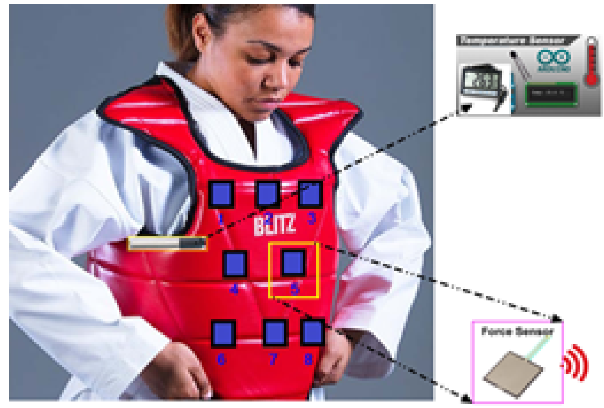


Figure 3. Implementing and installing sensors on proposed system

data collected from sensors installed in the sport-jacket. On the other side, computers are used by the medical and controlling staff for real-time monitoring the status of the athlete's body (i.e. temperature, strike force, and the number of strikes that the athlete has been received from the opponent). Therefore, all sensors are integrated and collaborated to simultaneously measure any strong or abnormal hits in the chest and body of the athlete, and continuously monitor his/her body temperature.

The main architectural design is illustrated in Figure 2. This architecture explains the system circuits to be installed. The Proteus plotter is used to design and draw the diagram of architectural design for the proposed system. This Proteus plotter tool is typically used in order to virtually test the compatibility of running different parts of hardware like sensors, Arduino Mega card and other resistors and all components together. This plan enables the designers to test the suitability of the architectural design. Then, they can search for the most compatible sensors, devices and controllers, before starting the installation process. Meanwhile, the block diagram of smart jacket flowchart is presented in Figure 3. At this point, the successful implementation of the proposed system is performed by integrating all components with each other, and then starting to develop the required programs to successfully run the proposed IoT-based system.

B. Monitoring & sensing process

The proposed IoT-Sports Health system mainly consists of eight force sensors and a temperature sensor. Figure 4 illustrates the places of distributing and installing these components at the protective vest chest-guard, which is well-known as a sport-jacket. The installed temperature sensor is the waterproof sensor of DS18B20 probe, which continuously measures the temperature without needing for reset like other devices [31]. This temperature sensor measures the range from -55oC to +125oC, which needs to be normalized and converted to the range from +20oC to +45oC similar to the temperature scale of human-body [31], [32].

The most commonly used device to measure the strength of the hits is the force sensor [31]. Eight sensors of force-sensing resistor (FSR) devices are installed as seen in Figure 4. They can sense any hit and measure its strength and directly transmit the recorded data using wireless communication through the connected Wi-Fi ESP8266 module [33]. Therefore, any hit or strike received by each force sensor in the athlete-jacket from the opponent is measured, recorded, and directly sent for analysis. A converting algorithm is adapted and developed to convert and normalize the recorded force values as given in Equation 1:

$$y_i = P_i x_i, \tag{1}$$

where x_i is the digital value of hit strength generated from the force sensor. P_i refers to the threshold values used by the converting algorithm to normalize the strength of the hit and convert it to the corresponding value. y_i is the final output value to be used for analysis purposes. The range $1 \leq i \leq n$ refers to the number of FSR sensors, where n equal to eight sensors in our proposed IoT-Sports Health system. These sensors are installed to cover all the front area of the sport-jacket, and they are sufficient to accomplish the monitoring process. The magnitude value of y_i is the final output of Equation 1, where this magnitude is categorized into three levels, which are classified to low strength hit, med strength hit, and high strength hit. This categorized process is classified in order to detect and determine each hit if it is dangerous and causes a severe strike to the athlete's body during the training session.

At the same time, the sensor of DS18B20 probe continually measures the body temperature and sends all measurements via a wireless connection. However, this temperature sensor requires an adjustment process. Therefore, we adopt a calibration method from [34], to calibrate the measured data acquisition in order to be integrated with Arduino IoT-based system. To reduce the error readings of the temperature DS18B20 sensor, the fitting value (FV) and K-type of steady condition are also calculated based on the calibration

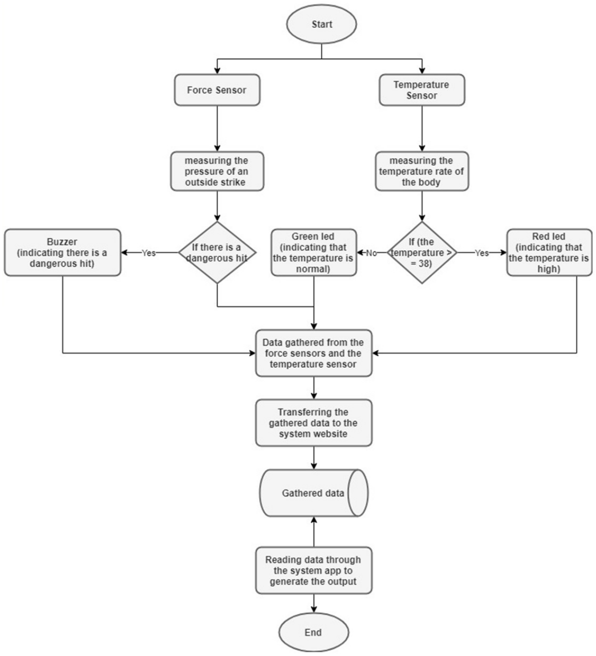


Figure 4. Flowchart of proposed system

method adapted from [35]. Finally, all measured data from the eight FSR sensors and the temperature DS18B20 sensor will be normalized and analyzed in the main server node of our proposed IoT-based system. The results obtained from our experiments are discussed in the next section.

4. Experimental Results

In this section, the experimental process for testing the performance of our proposed IoT-Sports Health system is discussed. The prototype of the proposed IoT-based system used the Arduino Mega microcontroller, attached to the mini-breadboard panel, which is the main base to attach other components, sensors, and devices. There is no need to solder or weld this breadboard. This flexible feature makes the prototype reusable for implementing different models, in order to test the designed circuits [36]. ESP8266 Node MCU Wi-Fi is the widely used wireless connection system on chip (SOC) module for installing IoT-based systems [37].

The main sensors are force and temperature devices that are embedded within the sport-jacket. Eight force sensors are installed in the front part of the sport-jacket to sense the strength of any hit, and directly sending the read data to the control staff and medical team. Practically, any abnormal or strong hit harms the athlete, and then it may increase the temperature of his body. Therefore, our proposed IoT-based system is developed to detect the hits, and directly alerts the control medical staff with any strong critical hit through analyzing and transforming the measured readings. In order to test the performance of our proposed system, real experimental tests are evolved during three different types of Mixed Martial Arts (MMA) sessions.

Therefore, the process of experiments is expansively done to evaluate the proposed system. The output results from this experimental process proved the efficient out-performing of our proposed IoT-based Sport jacket when compared with similar existing systems in respect to the accuracy of measurements and the fast response time. Figure 5 depicts the recorded angular signal of consecutive hits that are detected by used force sensors [38], [39]. These signals illustrate the angular velocity for varying punches of kick-boxing. These samples of rotational signals represent the pulse waves of hits, which can be analyzed to conclude the strength of each hit or punch.

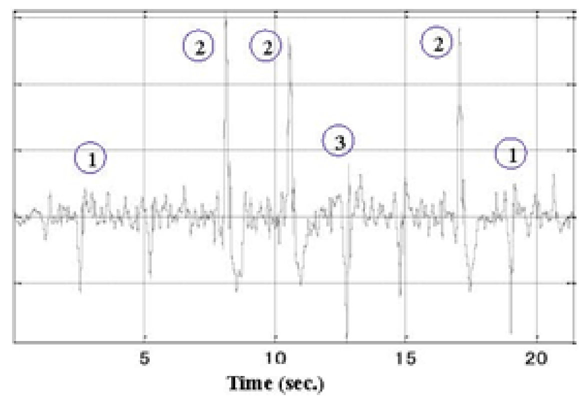


Figure 5. Three varying types of hits (low, mid, high) from signals of angular velocity for force punches

The analysis process explains three main different types of punches, which are categorized as low, medium, and strong hits with respect to the numbered angular velocity. In the experiments of our proposed system, the signals of low and medium hits are considered to be normal punches while the high velocity-like pulses in number (2) in Figure 5, are reflecting from strong punches. Therefore, the analysis algorithm of our proposed system will directly notify the control and medical staff. This nonfiction indicates that the player is strongly punched and these heavy hits may cause serious damages to the player.

Such notification alerts the control team to pay attention to what's happening. The control team may stop the match or making time out to detect the status of the athlete's body. A specialist from the control team cooperated to perform a real study using nine sessions for three different types of matches (Kickboxing, Karate, and Taekwondo). This team works as experts to monitor and manually register the number of hits in each session. Also, they reported the scale of each punch and classify it, if it is a strong hit or a normal one. Finally, comparative analysis is computed from the readings that are obtained by our IoT-Sports Health system, to record the number of hits and report the level of each hit. Then, the number of alerts that our proposed system notifies the control team is also reported. Table II summarizes the comparative results and calculates the mean of accuracy results.

TABLE II. Comparative Experiments of Proposed Method for Recorded Results in Three Different Types of Matches

Match with sport-jacket (session)	# of hits	Expert Opinion of punch strength	Notify of Proposed IoT-based	# incorrect alerts by Proposed System	Rate of Accuracy %
Kick-Boxing	60	25	27	2	92%
Karate MMA	70	40	43	3	93%
Taekwondo	50	25	23	2	94%
Kick-Boxing	55	30	32	2	93%
Karate MMA	75	35	27	2	92%
Taekwondo	60	30	33	3	94%
Kick-Boxing	45	22	26	4	89%
Karate MMA	67	35	37	2	96%
Taekwondo	47	25	21	4	90%
				Mean of Accuracy (Avg.)	92.5%

The results showed the reliability with a steady and direct response from our proposed IoT-based system. Figure 6 show the column chart for the average accuracy rates that are obtained by our IoT-Sports Health system. This pictorial chart depicts the performance of the proposed system in experimental process. In conclusion, our IoT-Sports Health system achieved the best accuracy results compared with actual results of the expert real observation. These efficient outcomes promote our proposed system to be feasible and to be deployed in practical monitoring health systems.

5. Conclusion and Future Work

In this paper, a new IoT-based system is proposed to monitor the health of sportspeople during the dangerous athletics like Mixed Martial Arts (MMA). The main key of our proposed system is to simultaneously detect the strength of hits to the front body of athlete and to keep a record of athlete temperature. The prototype of the proposed IoT-based system is installed within a sport-jacket that is typically dressed by player in MMA training sessions. Eight force-sensors are used to read the strength of the punches that the athlete has been received from the opponent. The collected readings are analyzed and directly sent to the control team, in order to alert the medical staff for

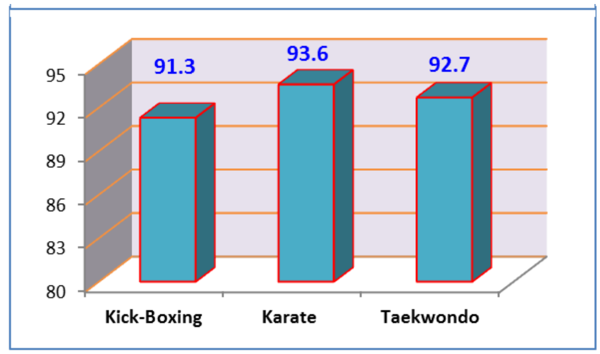


Figure 6. A column-chart of accuracy for final outcomes

any strong hit that may cause danger to the body of the athlete. The experimental comparative results proved the efficiency of our proposed system and proved solid and steady response as a real-time monitoring system.

In the future we plan to build a more modernized smart IoT-based system by installing the latest technological devices for sensing the force of punches. We recommend extending the comparison process to use the accuracy ratio in future works like prediction ratio analysis, Error rate determination, and F1 score ratio. We also plan to extend our methodology to be used for monitoring aging people that are suffering from chronic diseases that stay in-home.

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