IOT-BASED SOLUTION TOWARDS REAL-TIME MONITORING SYSTEM FOR HIGH JUMP SPORT

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To everyone who supports me, it just begins...

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ABSTRACT

In high jump sport, approach speed is one (1) of the important parameters to maintain the speed as well as to gain good momentum at the ankle during the take-off. The good approach speed can prevent injury at the ankle for the athlete. Today, high jump athletes still use high-speed camera to guide them in training by capturing all of the athletes' movements. This is because, there is no wearable device that can monitor the athlete performance during the training in real-time. Thus, the aim of this study is to develop a wearable Internet of things (IoTs) device that measures the speed during the approach speed and force during the take-off to help athletes to improve the performances and prevent injury at the ankle during take-off. This IoT device has implemented real-time monitoring systems (RtMS) that used IoTs as a connectivity which includes input, process and output. The input consists of global positioning system (GPS) sensor attached to the waist and force sensors placed at the bottom of the ankle as a wireless input for data capturing. These data is then being processed by microcontroller units (MCUs) with an embedded Wi-Fi module on the same chip that has been programmed and the results obtained are displayed on the mobile application (app). Other than that, there is a vibrator motor placed near the GPS sensor which acts as an actuator output that will vibrate according to the speed setting of the athletes. Apart from that, the latency and throughput of the two (2) different MCUs were also measured and compared to investigate the network transmission issues during the sport event. The ESP8266 MCU has been selected as the result shows that it has high throughput, low latency and small in terms of size compared to Arduino Yun Mini MCU. This system shows a significant result when intermediate athletes tested the devices with and without using the alarm system. Hence, it is shown that the implementation of wearable devices that monitored speed and force parameter helps to improve the performance of the athlete by following professional benchmark data.

ABSTRAK

Dalam sukan lompat tinggi, kelajuan adalah satu (1) parameter penting untuk mengekalkan kelajuan dan mendapat momentum yang baik di pergelangan kaki semasa melompat. Kelajuan yang baik boleh mengelakkan kecederaan di bahagian pergelangan kaki atlet. Pada hari ini, atlet lompat tinggi masih menggunakan kamera berkelajuan tinggi semasa latihan dengan merekod semua gerakan atlet. Ini kerana, tiada peranti boleh pakai yang boleh memantau prestasi atlet semasa latihan pada masa nyata. Oleh itu, tujuan kajian ini adalah untuk membangunkan satu (1) Objek Rangkaian Internet (IoT) peranti boleh pakai yang mengukur kelajuan semasa pendekatan kelajuan dan daya semasa lonjakan untuk membantu atlet bagi meningkatkan prestasi dan mengelakkan kecederaan di pergelangan kaki semasa lonjakan. Peranti IoT ini telah melaksanakan sistem pemantauan masa nyata (RtMS) yang menggunakan IoT sebagai sambungan dan mempunyai input, proses dan output. Input yang terdiri daripada pengesan sistem kedudukan global (GPS) yang melekat di pinggang dan daya pengesan diletakkan di bawah buku lali sebagai simpanan data input tanpa wayar. Data ini kemudiannya diproses oleh unit pengawal mikro (MCU) dengan modul Wi-Fi yang dibina di cip yang sama diprogramkan, dan keputusan yang diperolehi telah dipaparkan melalui aplikasi (app) mudah alih. Selain itu, terdapat satu (1) motor penggetar diletakkan bersama pengesan GPS sebagai output penggerak yang akan bergetar mengikut tetapan kelajuan atlet. Seterusnya, kependaman dan pemprosesan untuk dua (2) MCU yang berbeza telah diuji dan dibandingkan untuk mengkaji isu-isu penghantaran rangkaian semasa acara sukan. MCU ESP8266 telah dipilih, kerana keputusan menunjukkan ia mempunyai pemprosesan yang tinggi, kependaman rendah dan kecil dari segi saiz berbanding MCU Arduino Yun Mini. Sistem ini menunjukkan hasil yang ketara apabila atlet pertengahan menguji peranti dengan dan tanpa menggunakan sistem penggera. Oleh itu, ini menunjukkan bahawa pelaksanaan peranti boleh pakai yang memantau parameter kelajuan dan daya lonjakan dapat membantu meningkatkan prestasi atlet itu dengan mengikut data penanda aras profesional.

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	-	Three-dimensional
ANDROID	-	Open-source operating system used for smartphones and tablet computers
App	-	Application
FMG	-	Force-myography
FSR	-	Force sensing resistor
GPS	-	Global positioning system
GUI	-	Graphical user interface
I/O	-	Input/output
IMU	-	Inertial measurement unit
iOS	-	iPhone operating system
IoT	-	Internet of thing
LDR	-	Light detecting resistor
LED	-	Light emitting diode
Li-Ion	-	Lithium-ion
Li-Po	-	Lithium-polymer
M2M	-	Machine-to-machine
MCU	-	Microcontroller unit
MQTT	-	Message queue telemetry transport
OS	-	Operating system
PAN	-	Personal-area network
RF	-	Radio frequency
RtMS	-	Real-time monitoring system
UTHM	-	Universiti Tun Hussein Onn Malaysia
UUID	-	Universal unique identifier
Wi-Fi	-	Wireless-fidelity
WSN	-	Wireless sensor network

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CHAPTER 1

INTRODUCTION

1.1 Overview

Internet of thing (IoT) devices have its own attraction in the production and research community. Along the last decade, there has been increasing maximisation of the production margin profit by the development of the wearable device that help in many sports areas like run, football, basketball and tennis [1].

In addition to these sports application development, variety of system prototypes and marketable products have been produced to handle user's demand which aim to provide real-time data for health condition information gained from the athlete or improvement data to increase the athlete performance or technique. These data are very useful to the coach, to monitor their athletes progress activities and to change the method of training from low to high performance in winning the sports competition. There are a lot of wearable sports device [1]–[6] in the world. However, there is no wearable device for high jump athletes. Most of the device are focussing on bigger sports competition like football and run [7]–[9].

1.2 High Jump Sport

High jump [10] is one (1) of the track and field sports in which the athletes must jump individually over a horizontal bar placed at measured heights without dislodging it. At the professional level, athletes run towards the bar and use the Fosbury Flop method of jumping, leaping head first with their back to the bar. The simplest technique for clearing the bar is the “Scissors Style”, in which a straight run-up is used. Then, the evolution of high jump techniques has been improved by the following techniques known as the “Western Roll”, the “Straddle” and the last is “Fosbury Flop”, which is commonly used at present as shown in Figure 1.1 [10].

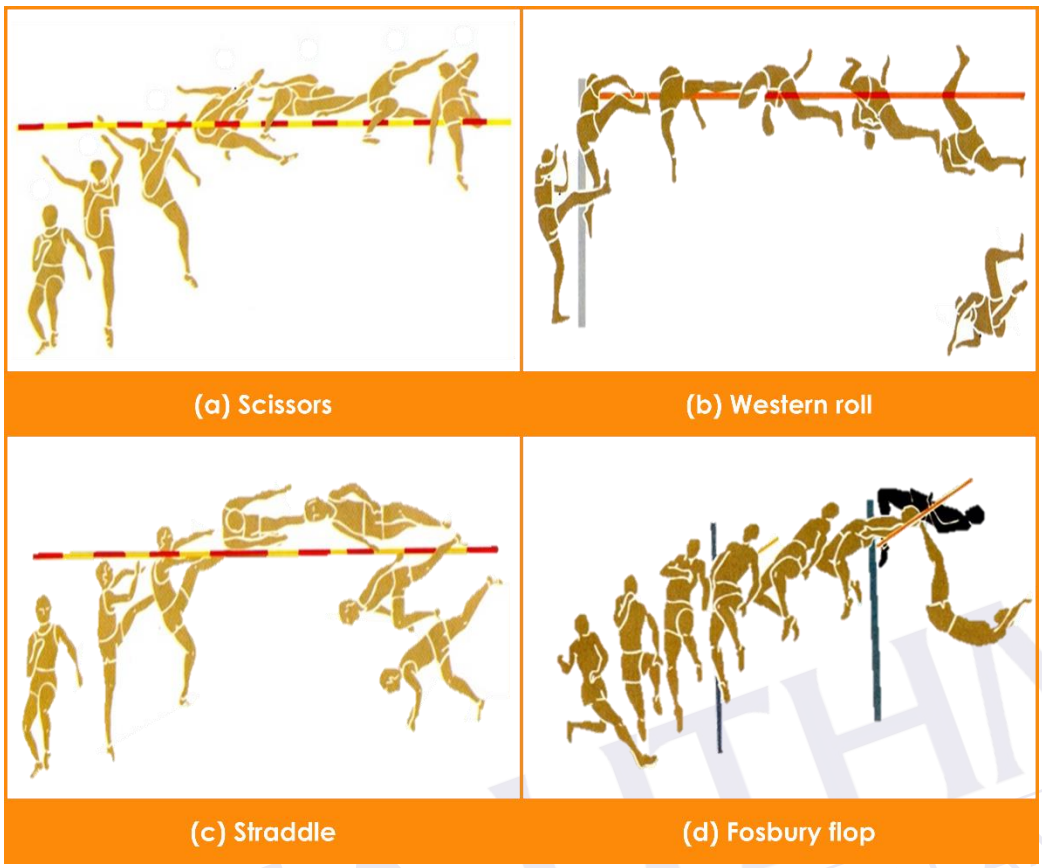

Figure 1.1: Techniques used by high jump athletes [10].

To complete the jump, athletes need to perform three (3) stages of actions including approach run, take-off jump and the flight phase. These actions are illustrated in Figure 1.2. The approach run is the main important part to the high jump, most athletes [10], [11] perform the run at speed of $7ms^{-1}$ before the take-off. The speed is used to control the take-off jump. Most intermediates and professionals can run at more than $7ms^{-1}$ [12]. During the run, the athlete will continue to speed up in a straight line until they reach the J-turn. Athletes tend to slow down from approach run to take-off and the body will bend down slightly inward at a J-turn to create a force at take-off, which slows down the athlete, hence it minimises the speed of the body and increases the control during the take-off [13]–[16].

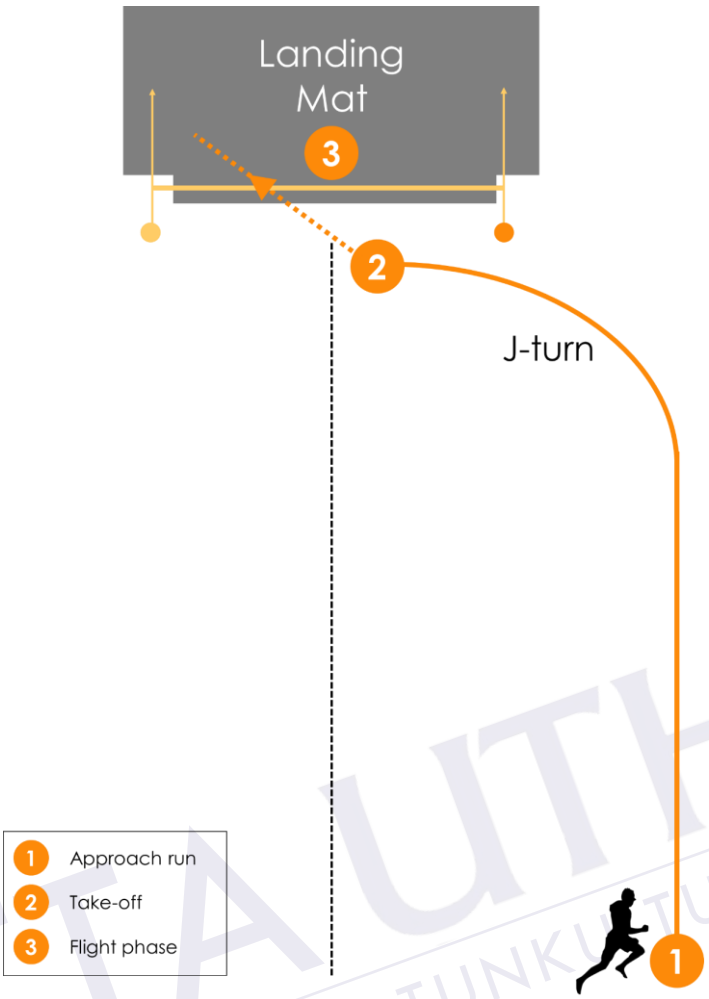

Figure 1.2: Overall stages to complete the high jump.

At the second stage, the take-off is done at moderate speed. To achieve the best jump during take-off, athlete needs to use centrifugal force to get around the J-turn and jump to cross the bar as illustrated in Figure 1.3. Many athletes are unable to perform the jump at maximum height due to the overuse of the ankle. This is due to some of them running below or more than the moderate speed. The low approach speed can cause high pressure to the ankle that causes the athlete to be unable to provide momentum to the body before the take-off [17]. Meanwhile, high approach speed can cause uncontrollable jump that will affect the body flight phase as it will cause a failure of crossing the bar.

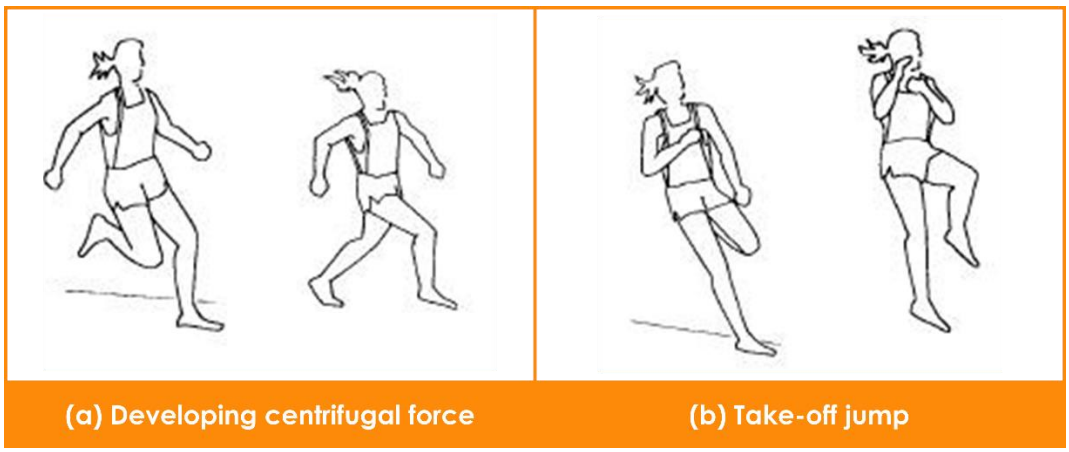

Figure 1.3: High jump take-off position [10].

The last stage is the flight phase which is common among most of the athletes to cross the bar. At the flight or jump phase that takes place after the take-off; to get to this stage, the athlete must swirl around the axis of the horizontal bar line until their backs are over the bar as they cross it. The athlete needs to curl out the body by approaching the bar and then curl in the body after passing the bar as shown in Figure 1.4. Then, it finishes with the landing of the athlete behind their upper body on the landing mat.

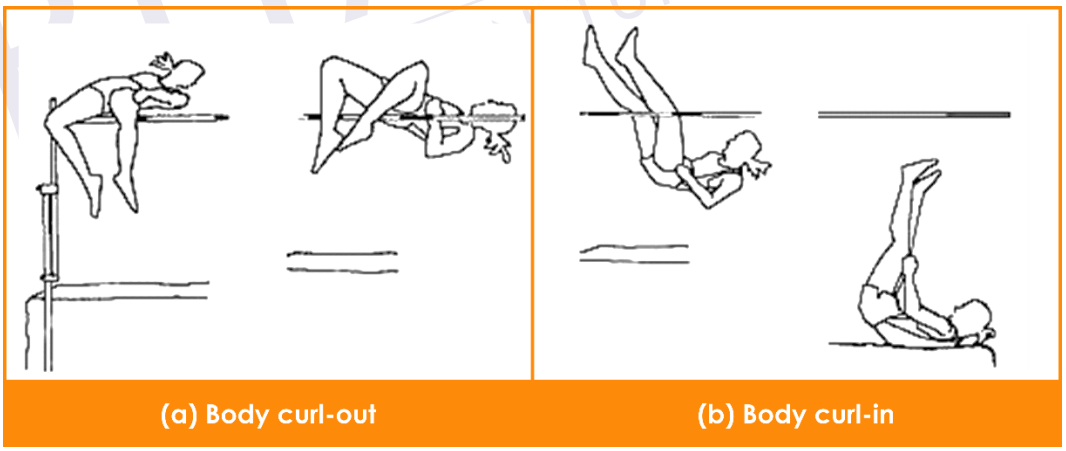

Figure 1.4: High jump body position during the flight phase [10].

1.3 Conventional High Jump Sport Monitoring System

The high jump athletic performance and improvement of the record level depend on many variables. Conventionally, most of the high jump athletes used vision system [11]–[13], [17]–[27] that is high-speed camera to view their image data as shown in

Figure 1.5. However, these data need to be analysed by the researchers first, before the final result are produced and given to the coaches and athletes. This outdated vision system is inefficient and costly.

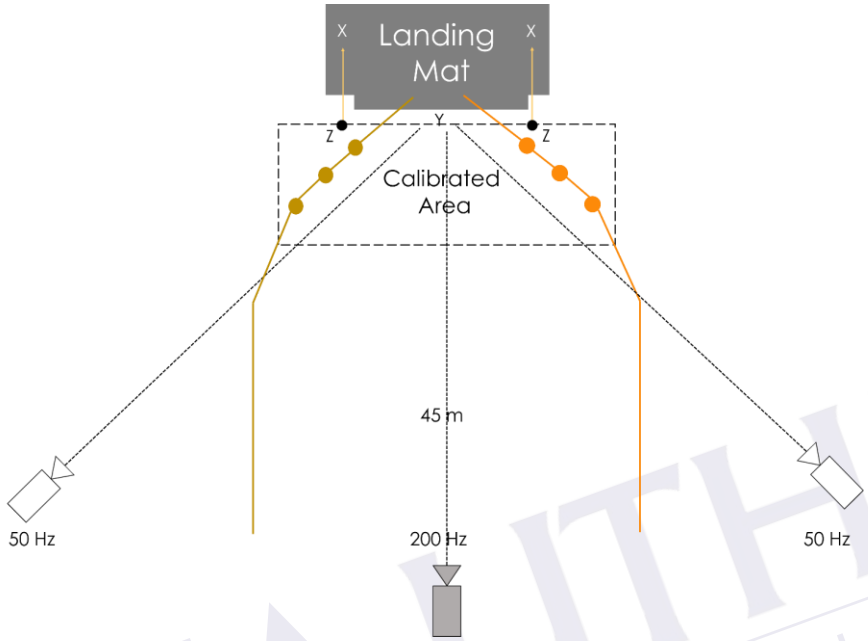

Figure 1.5: Vision system used in high jump sport [11]–[13], [17]–[27].

In the recent years, high jump athletes performances were analysed by using high speed camera to capture the approach speed, take-off force and angle of the leg during the jump [10], [13], [20], [22]–[24], [28]. Table 1.1 demonstrated high jump parameters detection using high speed camera. The data captured by the high-speed camera are in raw data. Thus, it needs to be simplified using algorithms to make it user-friendly for athletes and coaches to visualise and analyse the data every time the procedure ends which results in the waste of time. The experimental procedure is only capable to be carried out by professional technical support that is responsible to setup and calibrate the camera. Other than that, this procedure is high in cost as the sports institution needs to have a good financial support to pay for the expensive and high maintenance of the high-speed camera, and also the professional technical support team itself.

Table 1.1: High jump parameters detection using high-speed camera.

Year	High-speed camera	Parameters			Refs.
		Speed	Force	Angle	
1997	Prisma Millipede III, Apex Target and HR48TDS	✓	✓	✓	[10]
2005	Panasonic MS2 sVHS	✓	✓	✓	[13]
2006	Digital JVC DVL 9800	✓		✓	[20]
2007	Panasonic (NV-GS400) DV	✓		✓	[22]
2010	Mikrotron motion blitz cube eco-1	✓		✓	[23]
2010	N/A		✓	✓	[28]
2011	Sony VX1000 and NAC HSV-400	✓		✓	[24]

Thus, to improve the system, real-time monitoring system (RtMS) is used to provide real-time result, with the advanced wireless communication technology that communicate using wireless networks for activity recognition. Currently, RtMS [6], [29]–[44] has been applied to various applications and it is also an important practical value for sports. It enables data administrators to review all processes and functions performed on the data in real-time and it can also be monitored through bar and graphical charts on a main monitor interface.

In sports, injury is inevitable, hence prevention is better than cure. The similar risk magnitude exists in this high jump sport where injuries tend to happen while jumping. Percentage of jumper to get injured is very high due to the fallibility of athlete jumping themselves [45]. Accidents, poor training practices, or improper gear can cause some athletes to get hurt due to their fitness level like not practicing warming up or enough stretching that can lead to injuries [46].

Due to these concerns, high-performance and low-injury are crucial not only for athletes but also coaches. The coach needs to train the athletes to improve their performances at maximum level to win the game. However, to do that, it can cause injury to the athletes if they exceed their limit. Currently, most of the study such as in [13], [14], [16], [23] used a computer simulation model to investigate various considerations that affect optimum peak height and torque in a high jump. This study explains the improvement of the athlete who jumps at maximum height with a strong torque. Unfortunately, there is no hardware implementation of high-performance and low-injury to monitor both parties; athlete and coach.

To paint a comprehensive picture of the central issues in high jump sport monitoring system, several research papers have been analysed and then illustrated in a form of a timeline as shown in Figure 1.6.

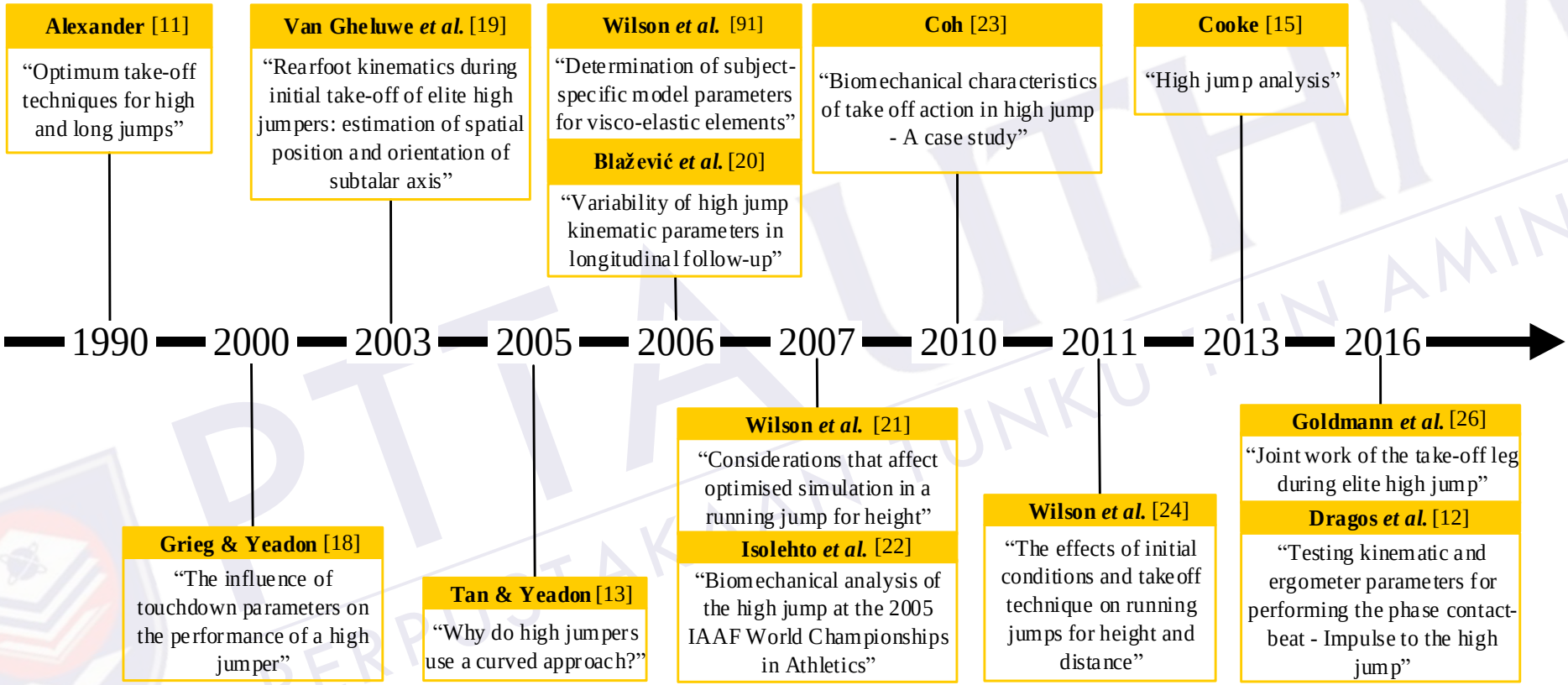

Figure 1.6: Survey on high jump sport.

1.4 Real-time Monitoring System

In computer science, real-time system (RtS) [6] is the data that are transferred instantly after the collection from certain input devices. There is a small process delay called latency between input data collection and output data desired in the timeliness of the information transported. RtS data is regularly used for navigation or tracking like GPS sensor that detects the current location of the object. Meanwhile, non-real time system (NRtS) is a term referred to define a method or result that incapable occurs immediately. For example, in sport, camera is used as hardware to capture the data of the athlete during training. The data are then being analysed to produce the results by the researcher and this process could be considered NRtS as researchers are regularly unable to produce the results immediately and it occasionally takes more than hours or even days [23].

RtS is also frequently connected with the monitoring system. It is the systematic observation and recording of events taking place in a task or programme. It is a technique of consistently collecting data information on all aspects of the monitoring project. Monitoring devices are used to constantly keep track on the status of the system in use. For example, servers, networks, databases, security, performance, website, internet usage and applications are tools that maintain the monitoring system.

Whereas, real-time monitoring system (RtMS) is a combination of process between real-time and monitoring system by which an administrator is able to analyse, evaluate and adjust the accumulation, removal, modification and use of data on software, database or system. It allows data administrators to analyse the whole progressions and tasks implemented on the information in real-time.

Currently, RtMS is used at large in sports application [30], [34], [37], [41], [47]. Sport like football used RtMS to calculate and identify a potential injury, or avoid injury to improve performance in a game [30]. Other than that, a study has been implemented to monitor real-time data of the swimming athletes to improve any particular physiological or psychological limitation that possibly gave athletes a winning edge above their opponents [34]. The feasibility of smartphones are also used in a real-time monitoring environment for sports applications [37] and the real-time analysis of sweat and sodium levels during exercise is developed to handle the fluid system using wireless sensors [41]. Finally, a real-time method is then

implemented to observe and improve the jump landing performance to make the training more efficient [47].

The benefit of RtMS is that there is no major latency in response. The data are continuously up to date therefore providing the administration the ability to control immediate action while responding to result, problem or situation in the direct conceivable period of time. It could also give the administration the ability to improve understandings from the resourceful data to distinguish patterns for potential identification of either chances or threats to the system.

1.5 Wearable Devices

Semiconductor companies start to develop many types of device that are small and slim, to fit the human body without disturbing their body movement. The advanced biotechnology sensor implemented in the wearable devices [48], has their own purpose and it is capable to detect the human needs in their daily lifestyle like step tracking, pulse detection, position, calories burned and a lot more. The used of microcontroller unit (MCU) in wearable devices acts as the main controller to control the specific input of sensors and output of actuators. This MCU can be used in wearable device [29] to communicate to Internet or synchronise the data to the smartphone or directly to cloud server via wireless or wired communication systems as shown in Figure 1.7. The wired system has been widely used in the recent decade, but it has been slowly changed to wireless system such as the use of Bluetooth and wireless-fidelity (Wi-Fi). This is because, Bluetooth and Wi-Fi are more convenient to the user's perspective and easy to connect. It minimises the cost production of copper wire and increases the use of radio frequency (RF) over the world.

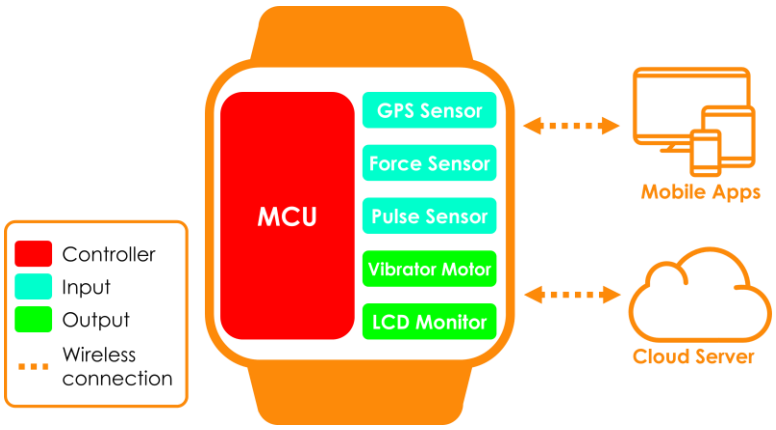

Figure 1.7: Example of wearable device.

Mobile applications (apps) are among the common downloaded applications every day that connect people throughout the Internet via social media like Facebook, Twitter, WhatsApp and others [49]. By using this apps, users can share many activities in their daily life. There are millions of sport apps that function to maintain user fitness level by using wearable device. The advanced feature of wearable device is that users like athletes in sports can send performances result to their coach by sharing their performance activity logs. Meanwhile, the coach will just analyse the athlete's data from the mobile apps anywhere they are using RtMS, without having concern to go to the sports centre every day. By having this technology, the coach can focus on how to improve the athletes' performances by reading through all the results from the smartphone.

1.6 Internet of Things (IoTs)-based Solution

IoTs are a structure of physical things embedded with sensors, processing units, actuators, software and connectivity to allow improvement of the performance by switching data information with other connected devices, operator or manufacturer [50]. The development of the IoTs in sports field is capable to improve the sports environment more efficiently in terms of injuries and performances.

The IoTs are game-changing. It is more than ever timely, given that sports organisations and teams are exploring networked and wearable devices, both in and out of the field, in diverse methods, such as:

(i) LED Indicator for Heart Rate Monitoring System [5];
(ii) validity and reliability of GPS devices for measuring movement demands of team sports [7];
(iii) sports performance analysis system using inertial measurement units, high-FPS video camera, and the Android platform [43];
(iv) suitability of strain gage sensors for integration into golf club smart sport equipment [36]; and
(v) system and method for wireless monitoring of sports activities [51].

Knowledge of capturing data on athletic event is not something new. Still, there is abundance of data available now and the speed is gathered definitely to improve the athlete's performances. Todays, many apps could be downloaded by sport fans to watch how the team performed and which players were the most dominant in the game. Anybody that has a Wi-Fi connection and smartphone in fact has a coach's eye view of the game.

Sports locations are no exclusions from IoT and sports researcher [8], and teams could have linked on this intelligence for sharing rich data information. Considerably, the influence of IoT in sports depends on the smart building idea for tying together current expertise resources. In this way, structure organisation software and structure administrator are aware of where people are, what they are doing and how much energy they use.

Besides, the IoT in sports also allows protection for players in a truly great approach [36]. Most sports are deliberated for only entertainment. Yet, some are undeniably dangerous for the players. That is why some manufacturers have constructed devices that are able to track this issue like a player who gets hit or fall for example. There is a sensor placed inside the helmet which calculates the impact and transmits the data to the coach and the medical team [1]. These assists the doctors to find out if it is safe for the players to remain in the field. Sports are among the fields that are truly capable to be developed by the IoTs system. IoT has definitely transformed the way games are played and watched.

REFERENCES

[1] K. Lightman, "Silicon gets sporty," *IEEE Spectr.*, vol. 53, no. 3, pp. 48–53, Mar. 2016.

[2] A. J. Salazar, "Wearable monitoring sports systems," *Found. Sci. Technol. grant. Gov. Port.*, 2010.

[3] A. Avci, S. Bosch, M. Marin-Perianu, R. Marin-Perianu, and P. Havinga, "Activity recognition using inertial sensing for healthcare, wellbeing and sports applications: a survey," in *2010 23rd International Conference on Architecture of Computing Systems (ARCS)*, 2010, pp. 1–10.

[4] D. D. Rowlands, L. Laakso, T. McNab, and D. A. James, "Cloud based activity monitoring system for health and sport," in *The 2012 International Joint Conference on Neural Networks (IJCNN)*, 2012, pp. 1–5.

[5] N. H. Mahmood, N. Uyop, N. Zulkarnain, F. K. Che Harun, M. F. Kamarudin, and A. Linoby, "LED indicator for heart rate monitoring system in sport application," in *2011 IEEE 7th International Colloquium on Signal Processing and its Applications*, 2011, pp. 64–66.

[6] D. A. James, L. Fanella, and R. Cusani, "Near Real Time Network Simulation for Team Sports Monitoring," *Procedia Eng.*, vol. 60, pp. 422–427, 2013.

[7] A. J. Coutts and R. Duffield, "Validity and reliability of GPS devices for measuring movement demands of team sports," *J. Sci. Med. Sport*, vol. 13, no. 1, pp. 133–135, Jan. 2010.

[8] M. Hedley and J. Zhang, "Accurate wireless localization in sports," *J. Comput.*, vol. 45, no. 10, pp. 64–70, Oct. 2012.

[9] M. Rahman, B. Carbunar, and U. Topkara, "Secure management of low power fitness trackers," *IEEE Trans. Mob. Comput.*, vol. 15, no. 2, pp. 447–459, Feb. 2016.

[10] J. C. C. Tan, "The mechanics of the curved approach in high jumping," © John Cher Chay Tan, 1997.

[11] R. M. Alexander, “Optimum take-off techniques for high and long jumps,” *Philos. Trans. Biol. Sci.*, vol. 329, no. 1252, pp. 3–10, 1990.

[12] B. Dragos, N. Mircea, B. Alexandru, and M. Ilie, “Testing kinematic and ergometer parameters for performing the phase contact-beat - Impulse to the high jump,” *Ovidius Univ. Ann.*, vol. 16, no. 2, p. 7, 2016.

[13] J. C. C. C. Tan and M. R. Yeadon, “Why do high jumpers use a curved approach?,” *J. Sports Sci.*, vol. 23, no. 8, pp. 775–80, 2005.

[14] V. M. Adashevskiy, S. S. Iermakov, and A. A. Marchenko, “Biomechanics aspects of technique of high jump,” *Phys. Educ. Students*, vol. 2, pp. 11–17, Apr. 2013.

[15] P. Cooke, “High jump analysis,” *Undergrad. J. Math. Model. One + Two*, vol. 5, no. 1, pp. 1–7, 2013.

[16] M. R. Yeadon, M. A. King, and C. Wilson, “Modelling the maximum voluntary joint torque/angular velocity relationship in human movement,” *J. Biomech.*, vol. 39, no. 2006, pp. 476–482, Jan. 2006.

[17] A. Burnett, “Jumping Injuries : Their Cause, Possible Prevention and Rehabilitation,” *elitetrack.com*. [Online].
Available: http://elitetrack.com/article_files/jumping-injuries.pdf.
[Accessed: 23-Dec-2015].

[18] M. P. Grieg and M. R. Yeadon, “The influence of touchdown parameters on the performance of a high jumper,” *J. Appl. Biomech.*, vol. 16, no. 4, pp. 367–378, 2000.

[19] B. Van Gheluwe, P. Roosen, and K. Desloovere, “Rearfoot kinematics during initial take-off of elite high jumpers: estimation of spatial position and orientation of subtalar axis,” *J. Appl. Biomech.*, vol. 19, pp. 13–27, 2003.

[20] I. Blažević, L. Antekolović, and M. Mejovšek, “Variability of high jump kinematic parameters in longitudinal follow-up,” *Kinesiology*, vol. 38, no. 1, pp. 63–71, Jun. 2006.

[21] C. Wilson, M. M. R. Yeadon, and M. A. King, “Considerations that affect optimised simulation in a running jump for height,” *J. Biomech.*, vol. 40, no. 14, pp. 3155–3161, Jan. 2007.

[22] J. Isolehto, M. Virmavirta, H. Kyrolainen, and P. Komi, “Biomechanical analysis of the high jump at the 2005 IAAF World Championships in Athletics,” *New Stud. Athl.*, vol. 22, no. 2, pp. 17–27, 2007.

[23] M. Čoh, "Biomechanical characteristics of take off action in high jump – A case study," *Serbian J. Sport. Sci.*, vol. 4, no. 4, pp. 127–135, 2010.

[24] C. Wilson, M. A. King, and M. Yeadon, "The effects of initial conditions and takeoff technique on running jumps for height and distance," *J. Biomech.*, vol. 44, no. 12, pp. 2207–2212, Aug. 2011.

[25] M. A. King, C. Wilson, and M. R. Yeadon, "Evaluation of a torque-driven model of jumping for height," *J. Appl. Biomech.*, vol. 22, no. 4, pp. 264–274, 2006.

[26] J.-P. Goldmann *et al.*, "Joint work of the take-off leg during elite high jump," *ISBS - Conf. Proc. Arch.*, vol. 33, no. 1, p. 3, 2016.

[27] F. Langer and A. Langerova, "Evaluation of the condition of high jumpers' locomotor system in the prevention of health problems," *Kinesiology*, vol. 40, no. 1, pp. 107–113, 2008.

[28] S. Martins, J. Carvalho, and F. Conceição, "Insights of take-off ground reactions force in high jump," *Int. Symp. Biomech. Sport. Conf. Proc. Arch.*, vol. 28, pp. 1–2, 2010.

[29] G. Liu *et al.*, "A Wearable Conductivity Sensor for Wireless Real-time Sweat Monitoring," *Sensors Actuators B Chem.*, Dec. 2015.

[30] K. Vuong, "PmSys: a monitoring system for sports athlete load, wellness & injury monitoring," 2015.

[31] P. Salvo, F. Di Francesco, D. Costanzo, C. Ferrari, M. G. Trivella, and D. De Rossi, "A Wearable Sensor for Measuring Sweat Rate," *IEEE Sens. J.*, vol. 10, no. 10, pp. 1557–1558, Oct. 2010.

[32] K. E. Iscoe, M. Corcoran, and M. C. Riddell, "High Rates of Nocturnal Hypoglycemia in a Unique Sports Camp for Athletes with Type 1 Diabetes: Lessons Learned from Continuous Glucose Monitoring Systems," *Can. J. Diabetes*, vol. 32, no. 3, pp. 182–189, Jan. 2008.

[33] A. J. Salazar, A. S. Silva, C. M. Borges, and M. V. Correia, "An initial experience in wearable monitoring sport systems," in *Proceedings of the 10th IEEE International Conference on Information Technology and Applications in Biomedicine*, 2010, pp. 1–4.

[34] J. Ride, C. Ringuet, D. Rowlands, J. Lee, and D. James, "A Sports Technology Needs Assessment for Performance Monitoring in Swimming," *Procedia Eng.*, vol. 60, pp. 442–447, 2013.

[35] S. Gupta, K. Shivam, D. C. Pandey, and P. Pratap Singh Gaur, "IoT based Patient Health Monitoring system," *J. Eng. Technol.*, vol. 04, no. 3, pp. 2316–2319, 2016.

[36] A. Umek, Y. Zhang, S. Tomažič, and A. Kos, "Suitability of Strain Gage Sensors for Integration into Smart Sport Equipment: A Golf Club Example," *Sensors*, vol. 17, no. 4, p. 916, 2017.

[37] M. W. McCarthy, D. A. James, and D. D. Rowlands, "Smartphones: Feasibility for Real-time Sports Monitoring," *Procedia Eng.*, vol. 60, pp. 409–414, 2013.

[38] E. Valchinov, A. Antoniou, K. Rotas, and N. Pallikarakis, "Wireless Health Monitoring System," *Wireless Mobile Communication and Healthcare (Mobihealth), 2014 EAI 4th International Conference on*. pp. 63–66, 2014.

[39] J. Heaffey, E. Koutsos, and P. Georgiou, "Live demonstration: Wearable device for remote EMG and muscle fatigue monitoring," in *2015 IEEE Biomedical Circuits and Systems Conference (BioCAS)*, 2015, pp. 1–5.

[40] M. Chen, Y. Ma, and E. Song, "Enabling comfortable sports therapy for patient: A novel lightweight durable and portable ECG monitoring system," in *2013 IEEE 15th International Conference on e-Health Networking, Applications and Services (Healthcom 2013)*, 2013, pp. 271–273.

[41] D. Morris *et al.*, "Wearable sensors for monitoring sports performance and training," in *2008 5th International Summer School and Symposium on Medical Devices and Biosensors*, 2008, pp. 121–124.

[42] Y. H. Henao and F. Fruett, "Development of an electromechanical sensor system to monitor sports activities," in *2009 9th International Conference on Electronic Measurement & Instruments*, 2009, pp. 4-6-4–10.

[43] J. P. V. Azcueta, N. C. Libatique, and G. L. Tangonan, "In situ sports performance analysis system using inertial measurement units, high-FPS video camera, and the Android platform," in *7th IEEE International Conference Humanoid, Nanotechnology, Information Technology Communication and Control, Environment and Management (HNICEM)*, 2014, pp. 1–6.

[44] M. Magno, L. Benini, L. Gaggero, J. P. La Torre Aro, and E. Popovici, "A versatile biomedical wireless sensor node with novel drysurface sensors and energy efficient power management," in *5th IEEE International Workshop on Advances in Sensors and Interfaces IWASI*, 2013, pp. 217–222.

[45] A. Tyflidis, G. Kipreos, A. Tripolitsioti, and A. Stergioulas, "Epidemiology of Track & Field Injuries: A One Year Experience in Athletic Schools," *Biol. Sport*, vol. 29, no. 4, pp. 291–295, 2012.

[46] "Jumping Injuries." [Online].
Available: http://physioworks.com.au/sports/jumping-injuries.
[Accessed: 20-Dec-2015].

[47] A. U. Alahakone and S. M. N. A. Senanayake, "A Real Time Vibrotactile Biofeedback System for Improving Lower Extremity Kinematic Motion during Sports Training," *2009 Int. Conf. Soft Comput. Pattern Recognit.*, pp. 610–615, 2009.

[48] B. Zhou, M. Sundholm, J. Cheng, H. Cruz, and P. Lukowicz, "Never skip leg day: A novel wearable approach to monitoring gym leg exercises," in *2016 IEEE International Conference on Pervasive Computing and Communications (PerCom)*, 2016, pp. 1–9.

[49] N. Gupta and S. Jilla, "Digital fitness connector: Smart wearable system," in *2011 First International Conference on Informatics and Computational Intelligence*, 2011, pp. 118–121.

[50] S. Dey, A. Roy, and S. Das, "Home automation using Internet of Thing," in *2016 IEEE 7th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, 2016, pp. 1–6.

[51] L. Razoumov, D. J. Bowen, and R. R. Miller, "System and method for wireless monitoring of sports activities," 26-Nov-2013.

[52] O. B. Lian, L. Engebretsen, and R. Bahr, "Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study," *Am. J. Sports Med.*, vol. 33, no. 4, pp. 561–567, Apr. 2005.

[53] S. Guangye, L. Wei, and Z. Yan, "The study on high jump athletes' special physical structure and training content."

[54] B. M. Nigg and M. R. Yeadon, "Biomechanical aspects of playing surfaces," *J. Sports Sci.*, vol. 5, no. 2, pp. 117–45, Jan. 1987.

[55] D. J. Farris, G. A. Lichtwark, N. A. T. Brown, and A. G. Cresswell, "The role of human ankle plantar flexor muscle–tendon interaction and architecture in maximal vertical jumping examined in vivo," *J. Exp. Biol.*, vol. 219, no. 4, pp. 528–534, 2016.

[56] "Long term periodisation of triple jump training," *Mod. Athl. Coach*, vol. 19, no. 1, pp. 12–14, 1981.

[57] E. Edwan, J. Zhang, J. Zhou, and O. Loffeld, "Reduced DCM based attitude estimation using low-cost IMU and magnetometer triad," in *2011 8th Workshop on Positioning, Navigation and Communication*, 2011, pp. 1–6.

[58] P. Pierleoni *et al.*, "A wearable fall detector for elderly people based on AHRS and barometric sensor," *IEEE Sens. J.*, vol. 16, no. 17, pp. 6733–6744, Sep. 2016.

[59] C. L. Roberts-Thomson, A. M. Lokshin, and V. A. Kuzkin, "Jump detection using fuzzy logic," in *2014 IEEE Symposium on Computational Intelligence for Engineering Solutions (CIES)*, 2014, pp. 125–131.

[60] M. B. H. Flores, C. M. B. Siloy, C. Oppus, and L. Agustin, "User-oriented finger-gesture glove controller with hand movement virtualization using flex sensors and a digital accelerometer," in *2014 International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*, 2014, pp. 1–4.

[61] A. Masdar, B. S. K. K. Ibrahim, D. Hanafi, M. Mahadi Abdul Jamil, and K. A. A. Rahman, "Knee joint angle measurement system using gyroscope and flex-sensors for rehabilitation," in *The 6th 2013 Biomedical Engineering International Conference*, 2013, pp. 1–4.

[62] M. Sakr and C. Menon, "Regressing force-myographic signals collected by an armband to estimate torque exerted by the wrist: A preliminary investigation," in *2016 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, 2016, pp. 1–4.

[63] F. Zabihollahy, B. M. Trindade, Y. Ono, and E. D. Lemaire, "Continuous monitoring of mechanical properties of plantar soft tissue for diabetic patients using wearable ultrasonic and force sensors," in *2016 IEEE EMBS International Student Conference (ISC)*, 2016, pp. 1–4.

[64] M. Wcislik, M. Pozoga, and P. Smerdzynski, "Wireless health monitoring system," *IFAC-PapersOnLine*, vol. 48, no. 4, pp. 312–317, 2015.

[65] K. W. Nixon, Xiang Chen, and Yiran Chen, "Footfall - GPS polling scheduler for power saving on wearable devices," in *2016 21st Asia and South Pacific Design Automation Conference (ASP-DAC)*, 2016, pp. 563–568.

[66] M. Maheedhar, A. Gaurav, V. Jilla, V. N. Tiwari, and R. Narayanan, "StayFit: A wearable application for Gym based power training," in *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2016, pp. 6290–6293.

[67] S. Thombre, "Performance analysis of IP based WSNs in real time systems," 2016.

[68] A. Bhatt and J. Patoliya, "Cost effective digitization of home appliances for home automation with low-power WiFi devices," in *2016 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, 2016, pp. 643–648.

[69] S. Thombre, R. Ul Islam, K. Andersson, and M. S. Hossain, "Performance analysis of an IP based protocol stack for WSNs," in *2016 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, 2016, pp. 360–365.

[70] M. Gentili, R. Sannino, and M. Petracca, "BlueVoice: Voice communications over Bluetooth Low Energy in the Internet of Things scenario," *Comput. Commun.*, vol. 89, pp. 51–59, 2016.

[71] E. Leão, C. Montez, R. Moraes, P. Portugal, and F. Vasques, "Superframe Duration Allocation Schemes to Improve the Throughput of Cluster-Tree Wireless Sensor Networks," *Sensors*, vol. 17, no. 2, p. 249, Jan. 2017.

[72] Y. Cheng *et al.*, "An approximate bandwidth allocation algorithm for tradeoff between fairness and throughput in WSN," *Wirel. Networks*, pp. 1–13, Feb. 2017.

[73] M. M. Kamal, S. S. Moni, and M. S. Alam, "MX-MAC: A Multichannel based low latency asynchronous MAC protocol for Wireless Sensor Networks," in *2016 9th International Conference on Electrical and Computer Engineering (ICECE)*, 2016, pp. 439–442.

[74] S. Khaliq and S. Henna, "HE-PRMAC: Hop extended pipelined routing enhanced MAC protocol for wireless sensor networks," in *2016 Sixth International Conference on Innovative Computing Technology (INTECH)*, 2016, pp. 392–397.

[75] I. Minakov, R. Passerone, A. Rizzardi, and S. Sicari, "Routing behavior across WSN simulators: The AODV case study," in *2016 IEEE World Conference on Factory Communication Systems (WFCS)*, 2016, pp. 1–8.

[76] F. A. Aoudia, M. Magno, M. Gautier, O. Berder, and L. Benini, "Poster Abstract: Wake-Up Receivers for Energy Efficient and Low Latency Communication," in *2016 15th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, 2016, pp. 1–2.

[77] "ESP8266EX Overview | Espressif Systems." [Online]. Available: https://espressif.com/en/products/hardware/esp8266ex/overview. [Accessed: 17-Mar-2017].

[78] "Arduino - Arduino Board Yun Mini." [Online]. Available: https://www.arduino.cc/en/Main/ArduinoBoardYunMini. [Accessed: 17-Mar-2017].

[79] P.-W. Lo Frank and M. Q.-H. Meng, "A low cost Bluetooth powered wearable digital stethoscope for cardiac murmur," in *2016 IEEE International Conference on Information and Automation (ICIA)*, 2016, pp. 1179–1182.

[80] C. Papatsimpa and J. P. M. G. Linnartz, "Coexistence performance model for a large ZigBee lighting sensor network in the 2.4 GHz ISM band," in *2017 IEEE 14th International Conference on Networking, Sensing and Control (ICNSC)*, 2017, pp. 465–470.

[81] Yun-Liang He, Shu-Qin Geng, Xiao-Hong Peng, Li-Gang Hou, Xiang-Kai Gao, and Jin-Hui Wang, "Design of outdoor air quality monitoring system based on ZigBee wireless sensor network," in *IEEE International Conference on Solid-State and Integrated Circuit Technology (ICSICT)*, 2016, p. 3.

[82] C. Chilipirea, A. Ursache, D. O. Popa, and F. Pop, "Energy efficiency and robustness for IoT: Building a smart home security system," in *2016 IEEE 12th International Conference on Intelligent Computer Communication and Processing (ICCP)*, 2016, pp. 43–48.

[83] A. Baniukevic, C. S. Jensen, and H. Lu, "Hybrid Indoor Positioning with Wi-Fi and Bluetooth: Architecture and Performance," in *2013 IEEE 14th International Conference on Mobile Data Management*, 2013, pp. 207–216.

[84] T. Ribeiro, O. Postolache, and P. Passos, "Performance assessment for mountain bike based on WSN and cloud technologies," in *2016 International Conference and Exposition on Electrical and Power Engineering (EPE)*, 2016, pp. 380–386.

[85] E. M. Kidman, M. J. A. D'Souza, and S. P. N. Singh, "A wearable device with inertial motion tracking and vibro-tactile feedback for aesthetic sport athletes Diving Coach Monitor," in *2016 10th International Conference on Signal Processing and Communication Systems (ICSPCS)*, 2016, pp. 1–6.

[86] N. S. A. Zulkifli, F. K. Che Harun, and N. S. Azahar, "XBee wireless sensor networks for Heart Rate Monitoring in sport training," in *2012 International Conference on Biomedical Engineering (ICoBE)*, 2012, pp. 441–444.

[87] A. Depari, A. Flammini, S. Rinaldi, and A. Vezzoli, "Multi-sensor system with Bluetooth connectivity for non-invasive measurements of human body physical parameters," *Sensors Actuators A Phys.*, vol. 202, pp. 147–154, Nov. 2013.

[88] Adafruit, "Using an FSR | Force Sensitive Resistor (FSR) | Adafruit Learning System." [Online].
Available: https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr. [Accessed: 24-Dec-2017].

[89] M. F. Roslan, A. Ahmad, and A. Amira, "Real-Time High Jump Wearable Device with ESP8266 for High-Performance and Low-Injury," *Int. J. Integr. Eng. – Spec. Issue 2018 Semin. Postgrad. Study*, vol. 10, no. 3, pp. 14–19, 2018.

[90] A. Ahmad, M. F. Roslan, and A. Amira, "Throughput, latency and cost comparisons of microcontroller-based implementations of wireless sensor network (WSN) in high jump sports," in *AIP Conference Proceedings*, 2017, pp. 1–9.

[91] C. Wilson, M. A. King, and M. R. Yeadon, "Determination of subject-specific model parameters for visco-elastic elements," *J. Biomech.*, vol. 39, no. 10, pp. 1883–1890, Jan. 2006.