Design, Development, and Evaluation of a Physical Exercise Monitoring and Managing System for Athletes

Conference Paper · November 2021

DOI: 10.1145/3487664.3487725

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Design, Development, and Evaluation of a Physical Exercise Monitoring and Managing System for Athletes

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ABSTRACT

The worldwide sports industry is booming through the usage of information and communication technologies. The collection, analysis, and presentation of athlete data is common practice for professional individual and team sports to assess individuals (athletes)/teams capability, fatigue, and subsequent adaptation responses; examine potential improvement areas, and minimize the risk of injury. Nutrition and exercise plans are also blended to meet specific training requirements and build strategic programs to maximize athletes' ability to perform. An effective and efficient system is required for the athletes and their mentors to monitor and manage the athlete's physical exercise. Therefore, the purpose of this article is to reveal the user requirements for creating an athlete monitoring system and to propose a wearable system based on the revealed requirements. To achieve these objectives, a Design Science Research (DSR) approach was adopted. As such, an empirical study (through semi-structured interviews) was conducted with 41 participants to reveal the system requirements; then a wearable athlete monitoring application was developed considering the revealed requirements. Finally, the proposed system was evaluated with 21 participants through the System Usability Scale (SUS) method. The study found that the proposed system is reliable, user-friendly, and useful for monitoring and managing physical exercise for the athletes and their mentors. The study also showed that the proposed system is useful and usable regardless of the athlete's age or gender.

CCS CONCEPTS

• **Human-centered computing** → *Empirical studies in HCI*; **Ubiquitous and mobile computing design and evaluation methods**; • **Information systems** → *Mobile information processing systems.*

KEYWORDS

Sportsperson, Cloud Computing, Edge Computing, Embedded Systems, Real-time Database, Software Systems

iiWAS2021, November 29-December 1, 2021, Linz, Austria

ACM ISBN 978-1-4503-9556-4/21/11. . . $15.00
https://doi.org/10.1145/3487664.3487725

ACM Reference Format:
Noor Nafiz Islam, Nafiz Imtiaz Khan, Md Abdur Razzak, and Muhammad Nazrul Islam. 2021. Design, Development, and Evaluation of a Physical Exercise Monitoring and Managing System for Athletes. In *The 23rd International Conference on Information Integration and Web Intelligence (iiWAS2021), November 29-December 1, 2021, Linz, Austria.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3487664.3487725

1 INTRODUCTION

With sports participation, capital, and labor traveling throughout the world since the 1970s, sports have posited an ever-increasing position inside the globalization of business and public events [33]. Major sporting events, such as the FIFA World Cup of soccer or the Olympic Games, have become extremely valuable commodities among countries and big cities throughout the globe [21]. In such an inexorable shift in the sporting industry, the need for an athlete monitoring system becomes very emergent as it provides valuable information on whether players are reacting adequately to specific training and competition needs [28]. Athletes are becoming more interested in and using sport and wellness technology products. Technology is being utilized to ameliorate not only training quality but also the quality of life, such as lowering the chance of injury. The desire for clear and easy-to-understand tailored information is increasing in tandem with the growing interest in sport and wellness technologies [14]. This may be addressed with digital coaching, which provides useful training data as well as advice and directions on how to enhance the training. Exercise monitoring data must be reviewed to ensure that athletes receive enough training to optimize their athletic abilities while also assuring that they respond to the training session effectively. By accurately measuring training volume, athletes' performance can be improved while simultaneously reducing the risk of injury caused by excessive exhaustion [5] [7].

Sports data can be quantitative or qualitative, and it may come from a wide variety of areas, including biometric data from wearable devices, camera footage, previous health records, on-field or on-route positioning tracking data, weather, and crowd statistics [30]. As players navigate across space throughout athletic events, wearable microelectronic mechanical (MEM) devices may capture a variety of biometric and geographical monitoring data [31]. Wearable devices such as pedometer anklets, chest bands, running or activity watches allow massive amounts of data to be collected, which falls under the category of big data because practically every positional movement a player makes can be logged.

Nutritional science is becoming more widely recognized in sports as a tool for affecting a player's stamina, productivity, and recuperation. This is a vital aspect of young athletes' sports performance, as well as allowing for proper growth and development. Macronutrients, micronutrients, and fluids, in the right proportions, are critical for growth and activity. Young athletes must learn what, when, and how to eat and drink before, during, and after-action to maximize performance [22]. Thus, Nutritional science must be considered as targeted therapy since even little adjustments may have a big influence on an athlete's performance. Clinical recommendations should be adapted to the individual player depending on the kind of sport, practice time and severity, and milestones in terms of weight and muscle mass [16]. Thereby, players should be assigned to a certified dietitian/nutritionist for a tailored diet plan [26]. Furthermore, the COVID-19 outbreak is forcing sport and exercise medicine doctors, as well as nutritionists, to reconsider how they provide the required assistance to players using eHealth and telecommunication options [3] [32] [12].

Therefore, the objectives of this study are as follows. First, to understand the fundamental requirements of developing a digital solution for ameliorating athlete fitness. Second, to propose a wearable system based on the revealed requirements.

The following is how the rest of the article is structured. Section 2 presents an overview of previous related publications on this topic. Section 3 briefly discusses the adopted research methodology. In section 4, the participant profile, study process, and results of the requirement elicitation study are delineated. The design and development of the proposed sportsmen system are briefly presented in Section 5. Section 6 contains the outcomes of the evaluation research. Finally, section 7 subsumes the study findings and provides outlines for future expansion.

2 LITERATURE REVIEW

This section briefly discusses the studies that are conducted in the past to promote assistive technologies for developing a collaborative application between athletes, coaches, and nutritionists to build team fitness.

Simpson et al. [24] tested the effectiveness of using the MealLogger, which is a mobile app that uses an image-based food record and social media features to offer personalized reviews for improving athlete awareness and nutrition-promoting behaviors. The study was replicated by 17 field hockey players from New Zealand aged between 18 to 20. According to the findings of this study, using such an app to monitor food consumption and to provide nutritional education to elite athletes is an effective way to improve their nutritional habits. In another study, Neumann et al. [20] investigated affective and attentional states of participants in a simulated running task. Similarly, Ding et al. [4] developed a platform named FEMO for free-weight exercise monitoring with RFIDs. The preliminary findings from 15 volunteers show that the developed platform FEMO can be used for a wide range of free-weight tasks and users, and can provide useful guidance for task alignment. Nonetheless, a rehabilitation exercise control and instruction system focused on Kinect was developed by Zhao et al. [34]. The authors developed a series of fundamental rule elements that can be used to articulate correctness rules for assessing and providing reviews on exercise efficiency in real-time. However, Rawston et al. [23] examined the measurement validity and data transfer efficiency of a remote telemonitoring device that included a wireless multi-parameter physiological instrument, a personalized smartphone app, and a middleware platform in people with sinus rhythm and Atrial Fibrillation (AF). According to the study, remote activity monitoring has the ability to supplement current cardiac recovery and heart rate control maintenance approaches by allowing patients to receive individually personalized treatment outside of typical hospital settings.

Gargiulo et al. [8] developed a device that includes a low-power Bluetooth module for wireless networking and is intended for long-term tracking during everyday activities. The device was used to track an athlete during a variety of physical activities, and in any event, a high-quality ECG was obtained, including when the athlete was fully immersed in freshwater. Another study was conducted by Foster et al. [6] focusing on monitoring the training, warm-up, and performance of athletes. The study revealed that simple indicators that would indicate imminent overtraining, or at least worsening overreaching, might be most helpful, while there exists a universal propensity for coaches and athletes to react poorly to temporary training or competitive incompetence by doing extra training. Thronton et al. [27] published a review paper that discusses a variety of approaches for analyzing athlete-monitoring data to aid and enlighten decision-making processes. This study found that in athlete-monitoring systems, practitioners can use a variety of analytical methods and tools. However, there are numerous aspects to consider while collecting data, methods for evaluating relevant changes, and there exist various data presentation approaches.

In sum, a limited number of studies were conducted focusing on the digital solution for making a complete team fitness management solution. Moreover, the applications available in the market are expensive [27] [25]. Low-cost athlete-friendly hardware coupled with an application interface is not available. Again, a few focused on the evaluation of mobile applications developed for athlete fitness and nutrition plan. Therefore, further studies are required to be carried out focusing on these issues to overcome the stated research gaps to some extent.

3 RESEARCH METHOD

To address the research objective, a design science research (DSR) approach was adopted as guided by Vaishnavi and Kuechler [29]. The overall research method was adopted from similar DSR studies [2], [18] and included the following five steps: (1) awareness of problem; (2) suggestion; (3) development; (4) evaluation; and (5) conclusion. The overview of the research methodology is shown in Figure 1.

In this study, it was defined that how to integrate hardware and software to create a system for monitoring athletes. Presently available systems, journals, and conference proceedings were reviewed to better frame the problem. The next step is suggesting a solution to the problem. It was proposed to develop a wearable system that could make a bridge between athletes, athlete mentors, and nutritionists. To identify the requirements for such a solution, a requirement elicitation study was conducted, interviewing 41 participants (athlete, athlete mentors, and nutritionist). The aim of these interviews was threefold: (1) to understand the scope of monitoring athlete physiological and athletic data that could be alleviated with

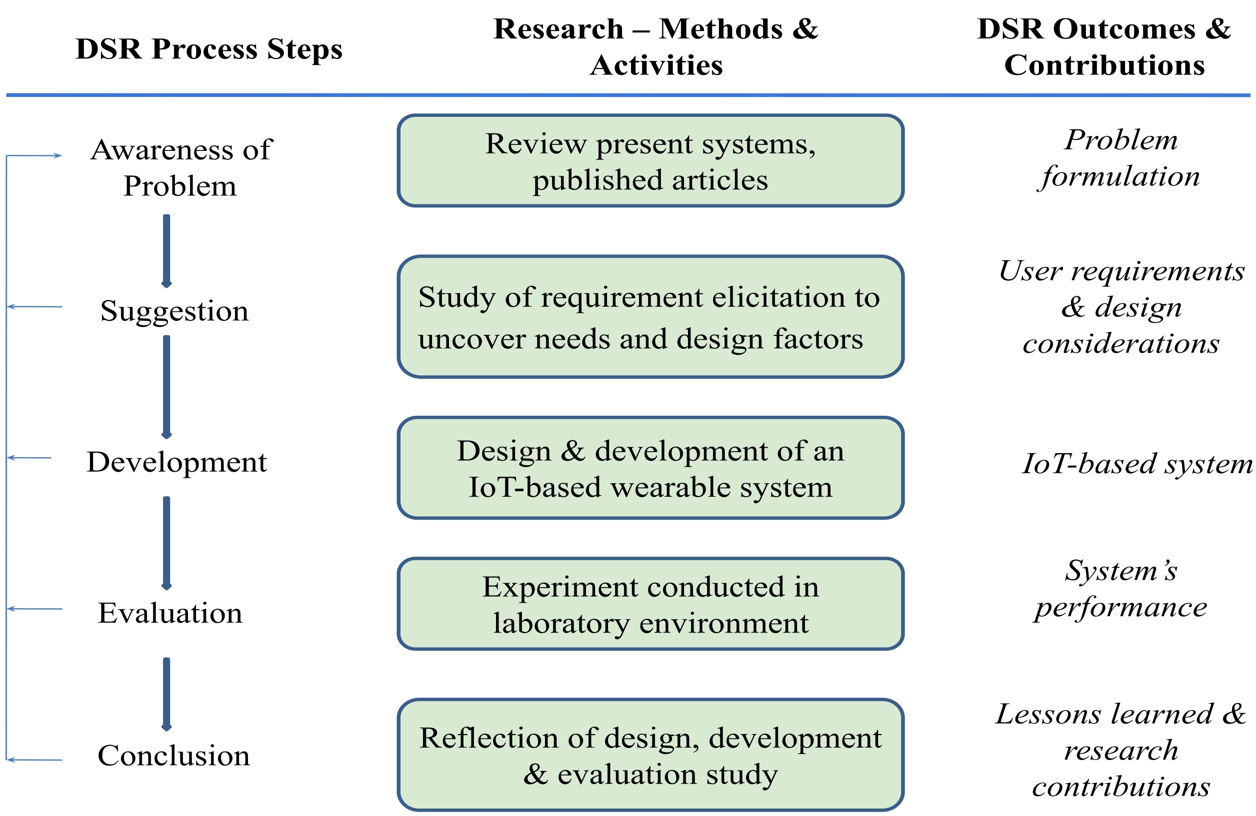

Figure 1: Overview of the research methodology (adopted from [29])

technology; (2) to reveal the functional and design requirements of the mentors to monitor and assign specific team/individual fitness goals and (3) to reveal the requirements of the nutritionists to monitor and assign diet plan to the athlete. A third step in the process is the development of the system. We developed a prototype in our lab based on the findings of step 2 and iterated the development process following agile software development recommendations. In the fourth step, we evaluated the feasibility of our solution both in a laboratory environment and in the field. This process included testing the usability of the solution as well as how it matched the design goals set for the system. In the fifth and final conclusion step, we present the main outcomes, contributions, and open issues for further investigation and research on this topic.

4 REQUIREMENT ELICITATION STUDY

4.1 Participants profiles

A total of 41 people (26 men and 15 women) with an average age of 24.5 years were interviewed. There were 28 athletes, 7 athlete mentors/coaches, and 6 nutritionists among the group. However, athletes can be further divided into three subgroups: professional, amateur, and recreational athletes. Among the 28 athletes, who were interviewed, there were 14 professional athletes, 6 amateur athletes, and 8 recreational athletes.

4.2 Study Procedure

Semi-structured inter-viewings were used to collect the study data. The consent of participants was obtained by email or a printed form in order to assure privacy and confidentiality. Ethics approval was granted by the author's institute's Research and Development (R&D) division. Each interview lasted approximately 10-15 minutes and was audio recorded. The audio recordings were transcribed and analyzed later on.

4.3 Revealed Requirements

The transcribed interviews were analyzed qualitatively by three independent researchers. The researchers separately read the transcribed interview data and coded the relevant pieces of information to match the actions, activities, and opinions of the interviewees. After the coding was completed, the researchers met together to compare the results of their coding. The inter-coder agreement [19] was 0.88. The disagreements were resolved by discussions. The concerns revealed through the qualitative data analysis were clustered into five broad categories. The categories are briefly stated as follows:

(1) **Health analytics**- It was identified from the interview that an athlete's heart rate and body temperature needs to be continuously monitored throughout the exercise time so that based on the health analytics, new tasks can be assigned to an athlete. If tasks are assigned not considering the health condition, the assigned task could overload an athlete.
(2) **Monitoring running speed**- Running is a common activity in all types of sports, like football, cricket, volleyball. Thus, how fast an athlete can move, track of this information needs to be kept so that new goals can be added based on the current performance.
(3) **Generating individual fitness reports**- One of the most important themes that emerged from the preliminary analysis as well as the interview data was the need for generating individual fitness reports. After completion of each athletic event/training session, an individual needs to see data about his/her physical performance. Athletes need to see statistics/graphs about his/her activity duration, distance covered, average pace, maximum pace, average speed, maximum speed, total ascent/descent, and calories burned information.
(4) **Enable team moderator to monitor and assign goals**- Team mentors need to assign teams/individuals with specific training. The mentor needs to check the improvement of the athletes as well so that fitness goals can be assigned to the individual based on the improvement of an individual,
(5) **Sports specific training plan**- Report based on specific games are required, which means a runner will get information which is related to running whereas, a footballer will get information related to football sports. According to this information, athlete mentors and nutritionists will provide inputs.
(6) **Enlist and maintain the food habits/diet plan of athletes** - Fitness coach/ nutritionist will access and assign food plan to athletes. They will assess an athlete's different physiological data like height, weight, athlete physical ability and assign a diet plan.
(7) **Design and functionality considerations** - The following eight considerations are proposed based on the interviews (1) big data as input - each athlete's data for a specific period is needed to be recorded ; (2) unique identification - each athlete needs to be uniquely identified via the system so that task can be assigned individually as well as fitness track of individual can be kept; (3) data accuracy - health-related (e.g. heart rate and body temperature) data needs to be accurate and reliable to assist the mentor and nutritionist plan accordingly; (4) light-weighted device – the wearable device need to be light-weighted to be comfortable to use and wear during the training period; (5) easy-to-use –the device needs to be easy to use to avoid technology stress and to make using it as easy as possible; (6) easy-to-learn – The system shall be made in such a way that all the stakeholders can easily use the system; (7) protect privacy – as the device is collecting personal health related information about the athlete, maintaining data privacy is paramount. (8) Durable– the wearable system needs to be durable to bear the wear and tear that happens during training.

5 PROPOSED WEARABLE SYSTEM

Based on the requirement elicitation study, a wearable system was designed and developed for athletes. The proposed system contains: a heart rate sensor to sense heart rate, a temperature sensor to monitor body temperature, an accelerometer to keep track of motion and the direction in which the athlete is moving. Furthermore, a Bluetooth transmitter was used to transfer data to the mobile.

5.1 System Components

A layered architectural view of system components is shown in Figure 2. The system includes three sensors, which are connected to an Arduino micro-controller. The Arduino connects the Bluetooth transmitter, synchronizing the sensor data to the mobile device. From athlete mobile device data is synchronized in database and mentors and nutritionist can see the athlete's data.

5.2 Prototype Development

The prototype development was divided into two parts: (1) development of the hardware device; and (2) development of the software device. In this sub-section, the development of both of the parts is presented.

5.2.1 Developing the Hardware Device. To develop the hardware device, the following versions of the sensors are used: (a) pulse sensor (SEN-00162) - a plug-and-play heart-rate sensor for Arduino to find the pulse rate as heart bit per minute (bpm), (b) temperature sensor (GY-906 MLX90614ESF) - to measure the body temperature in Fahrenheit scale, (c) accelerometer sensor (ADXL 335 Three-axis accelerometer)- to find out the speed and the direction. Apart from these; an Arduino Mega (microcontroller board) was used as a processing unit that intelligently controls the other sensors. All the sensors are directly connected with the microcontroller board in different pins. The microcontroller takes analog data from accelerometer, temperature, and heart rate sensors. These data are then sent via the Bluetooth Module HC-05 to the athlete's mobile. A 9V battery (MIS-00004) is used to give power to the device. Figure 3 showed how the sensors are connected with the microcontroller in our prototype. The overall workflow diagram of the system is shown in Figure 4. In the workflow of the system, at first, the wearable device synchronizes with the mobile app through a Bluetooth transmitter. To do the synchronizing, at first, the wearable device sends a request to sent (RTS) signal to the mobile app. The Bluetooth of the mobile phone needs to be kept on for synchronizing. The mobile app acknowledges the RTS signal by sending a clear-to-sent (CTS) signal. If the wearable device receives the CTS signal, it starts functioning. Next, the battery charge of the device is checked. If the battery charge of the device being less than 10 %, the buzzer will be on for two seconds, which will provide a reminder to the athlete to charge the device. Next, the sensors of the device are initialized and then the data is captured from the sensors. After capturing, the data is compiled and sent to the mobile app in a structured format. By receiving the data, the mobile

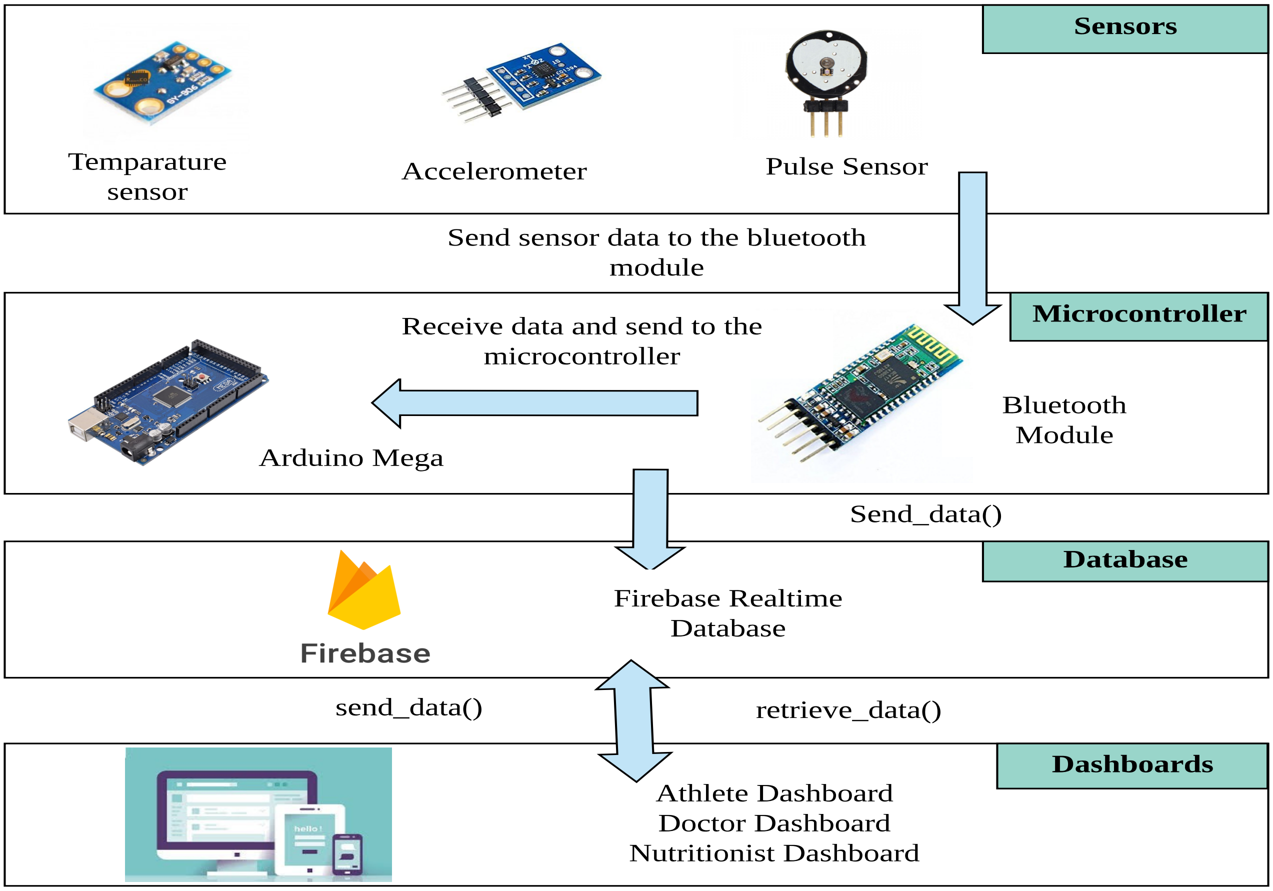

Figure 2: Layered architectural view of system components

app sends a acknowledge signal to the wearable device indicating that the data is received. After that, again the battery charge of the device is checked. Then for the charge being less than 2%, the device is turned off; otherwise, the same loop is repeated. Thus, in this way, all data from the sensors will be sent and saved to the mobile in a structured format. After the training/ exercise completes, the athlete can see the overall report of the session. Furthermore, athletes will be able to synchronize the session data with the cloud. After the data of a particular session gets synchronized with the cloud, the coach and nutritionist will be able to see the particular session summary in their respective dashboards, which subsumes: total running time, average heart rate, average speed, average body temperature, highest as well as lowest body temperature and heart rate.

5.2.2 Developing the Software Device. A smartphone app was designed that is connected to a cloud-based database. Figure 5 depicts a few prototypical interfaces of the developed application. Android studio [1] was used to develop the User Interface (UI) of this application, while Firebase [2] was used as the cloud-based database. The application has three main modules: the athlete module, athlete mentor module, and nutritionist module. From the wearable device's blue tooth transmitter data is received in an athlete's mobile. The mobile application receives the data. Once the application receives the data, it is stored in the database. A person can sign up in three roles: athlete, athlete mentor, or nutritionist. An athlete can view his/her personal health data (heart rate, body temperature, and running speed), can track the personal progress as well as can see the upcoming tasks, which have been assigned by the coach/athlete mentor, through the athlete's module. A coach can assign tasks to the athlete, can track individual athlete's improvement and health status by using the mentoring module. Lastly, a diet plan can be assigned to the athlete based on health condition by the nutritionist from the nutritionist module.

[1]https://developer.android.com/studio/intro
[2]https://firebase.google.com/

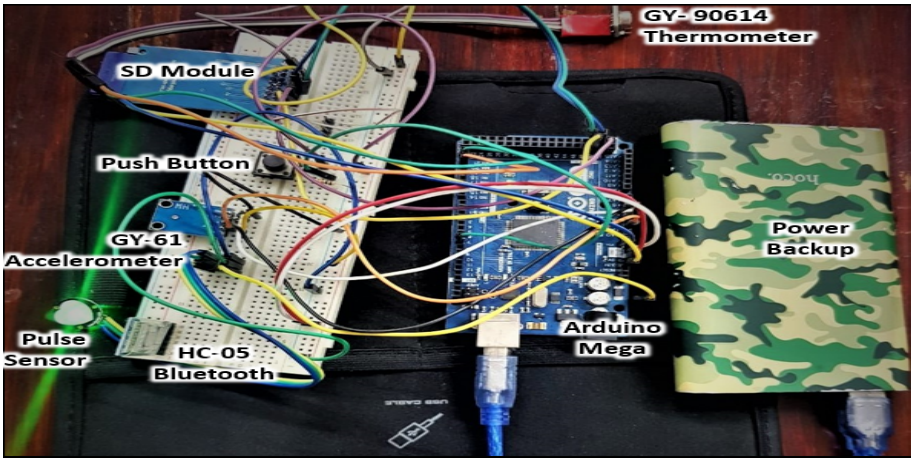

Figure 3: Hardware components of the prototypical system

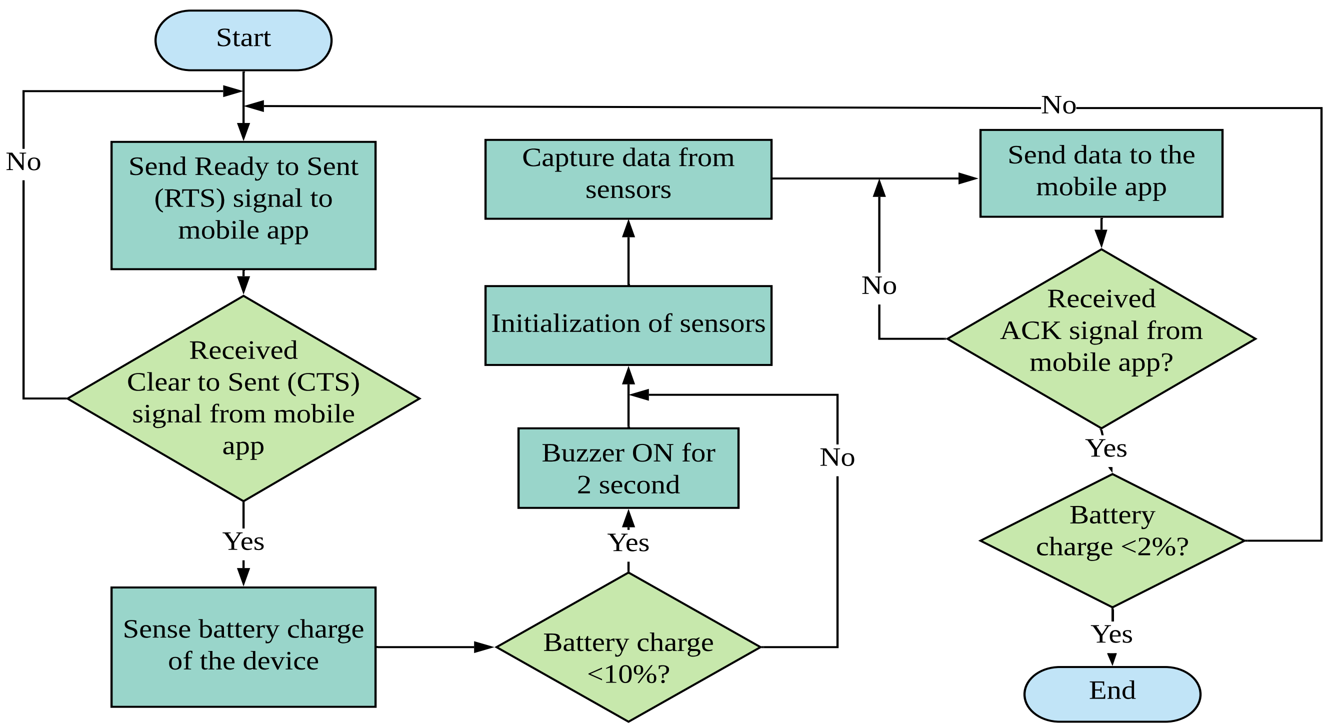

Figure 4: Work flow diagram of the proposed system

6 EVALUATING THE PROTOTYPE

Since usability is the key quality attribute for any digital system [9] [10] [11], the usability of the proposed system was evaluated. the System Usability Scale (SUS) [1] method was adopted to measure the system's usability as adopted in recent other studies [13] [15] [32]. The characteristics of the participants, the study technique, and the evaluation outcomes were briefly discussed in this section.

6.1 Participants Profile

A total of 21 professional athletes (12 male, 9 female) ranging in age from 16 to 42 years, having an average age of 23.45 years, were asked to participate in the evaluation study. As the system is designed for athletes, only professional athletes are invited to participate in the evaluation study. There were 12 cricketers, 7 footballers, and 2 hockey players among them. The internet, smartphone, and wearable system were all familiar to all of the participants. None

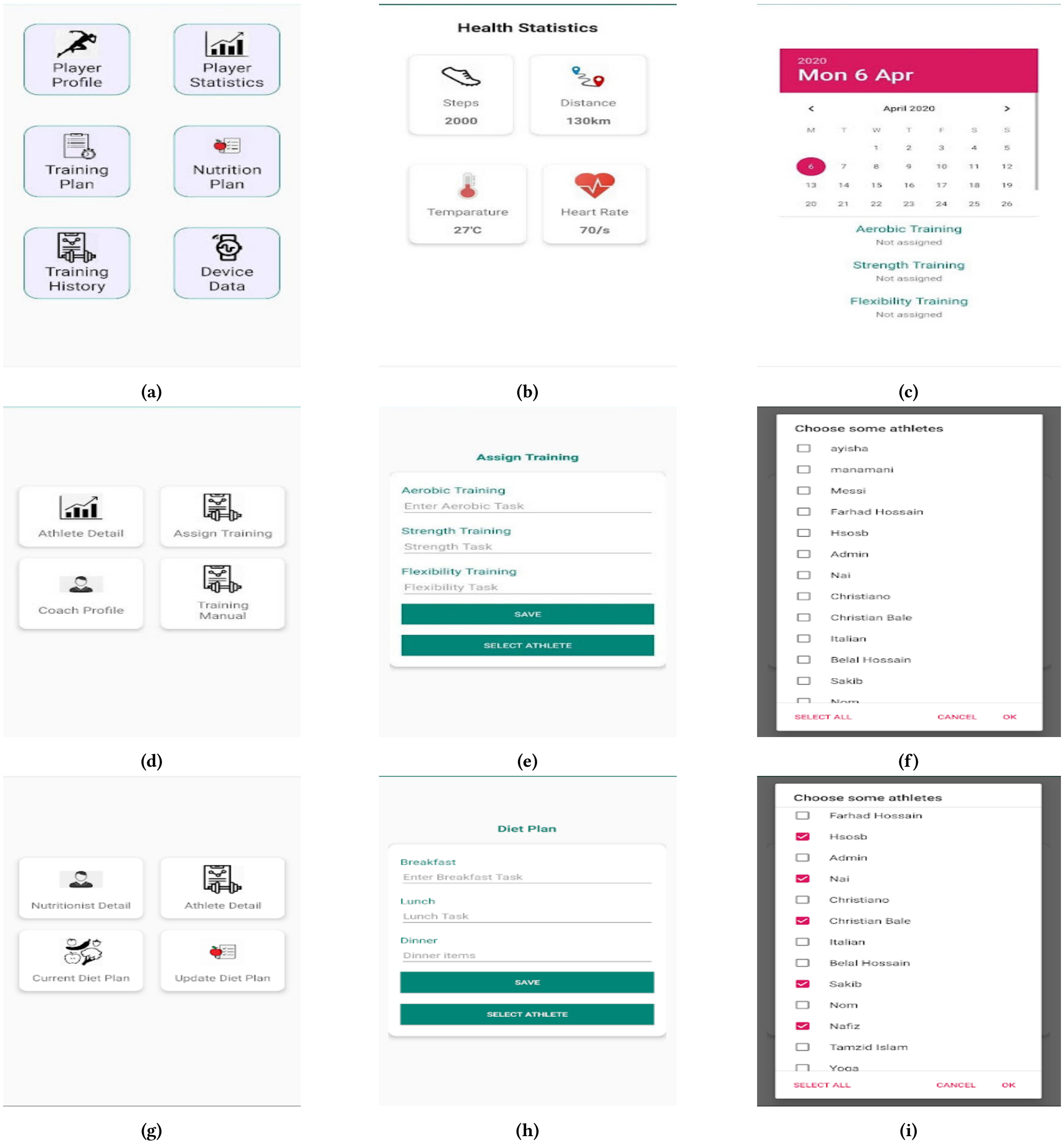

Figure 5: Few prototypical interfaces: (a) athlete modules, (b) viewing health statistics from athlete module, (c) viewing training history from athlete module, (d) coach module, (e) assigning training task from coach module, (f) selecting players for assigning task from coach module, (g) nutritionist module, (h) assigning diet plan from nutritionist module, and (i) selecting players for assigning diet plan from nutritionist module

of them have ever used the proposed system or any other similar system.

6.2 Study Procedure

The procedures below were followed for each test session. To begin, participants were apprised about the study's goals and required to sign a consent form. The system was then shown, and they were given 10 minutes to examine it. Finally, respondents were asked

Table 1: Results of the evaluation study (system usability)

Participants	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Raw Score	SUS Final Score
1	5	1	5	1	5	1	5	2	5	2	38	95
2	4	2	5	2	5	1	4	1	2	1	33	82.5
3	4	1	4	2	4	2	5	1	3	1	33	82.5
4	5	1	3	1	3	1	3	2	4	1	32	80
5	5	1	5	1	5	1	4	2	5	1	38	95
6	5	1	5	1	3	1	2	1	4	2	33	82.5
7	4	2	5	1	5	1	4	2	5	2	35	87.5
8	5	2	5	1	5	1	3	2	3	2	33	82.5
9	3	1	3	1	5	1	5	1	4	2	34	85
10	5	1	5	1	5	1	5	1	5	2	39	97.5
11	5	2	5	1	4	3	5	1	5	2	35	87.5
12	5	1	3	1	5	2	5	1	5	2	36	90
13	5	2	5	2	5	1	2	3	5	1	33	82.5
14	3	2	4	1	5	2	5	1	5	2	34	85
15	5	2	5	2	5	2	3	2	4	1	33	82.5
16	5	1	4	1	3	1	5	2	5	2	35	87.5
17	3	2	3	1	5	2	4	2	5	1	32	80
18	4	2	5	1	5	2	4	1	4	1	35	87.5
19	5	1	5	2	3	1	3	2	5	2	33	82.5
20	4	2	4	2	5	2	5	2	5	1	34	85
21	3	1	5	1	5	2	3	1	5	1	35	87.5
Average											**34.42**	**86.07**

to respond to 10 questions (statements) created according to the System Usability Scale (SUS) method. The surveys include issues such as the system's need and usefulness. Participants evaluated each question from 1 to 5 on how much they agreed with the provided statements (1: strongly disagree, 2: disagree, 3: neutral, 4: disagree, and 5: strongly agree).

6.3 Analysis and Result

The following approach was used to determine the SUS scores: To begin, we have deducted 1 from the score for each of the odd-numbered questions. Second, we have deducted 5 from the value of each of the even-numbered questions. Third, we summed up the entire scores, then multiplied the total scores by 2.5 to get the final scores, and last, we calculated the average of the final scores. Table 1 shows the outcomes of the SUS scores. The proposed system's total SUS score was found to be 86.07. According to [17], SUS scores of 0-64 are considered unacceptable, 65-84 are considered acceptable, and 85-100 are considered good. As a consequence, the participants' SUS score suggests that the proposed wearable system for athletes is practical and beneficial. Again, a t-test was used to test the two elements of the participant's profile. The two criteria are age (below 25 and equal to or over 25) and gender (male and female). Ten of the participants were under the age of 25, while the remaining eleven were over the age of 25. When considering the age factor, the t-value is 1.734 and the p-value is 0.063, however, when considering the gender component, the t-value is 1.872 and the p-test is 0.372. The results of the tests reveal that there is no statistically significant difference between these groups and that the developed application is useful and valuable regardless of the participants' age or gender.

7 DISCUSSIONS AND CONCLUSIONS

In this study, an athlete management system is developed that makes a bridge between athletes, athlete mentors, and nutritionists. It ensures better performance from the athlete as mentors can monitor group fitness levels at a glance. The usability of the proposed wearable system was tested with 21 professional athletes by using the System Usability Scale (SUS). On this scale, the proposed system's score was found to be 86.07 in the range of 0-100. According to the SUS score, it is evident that the proposed wearable system for athletes is a good fit to be used as an athlete monitoring and managing system.

The study has the following limitations. First, the developed prototype was not yet put in the form of an actual wearable device. While the basic system and usability requirements were met, additional testing with the next phase of the prototype is still needed before moving into production. Second, the affordability of the device was prioritized. The prototype was cost-effective, meaning that better system performance may be achieved in case the cost of the system is not an issue. Third, some aspects of the system such as using it while taking a shower or using it while sleeping were not tested. The system needs to be sweat proof and it has to be rugged. These issues will be taken care of in subsequent updates of the system.

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