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Endurance Track: A Comprehensive Embedded System for Equestrian Endurance Race Management

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Abstract: Digital transformation in horse businesses occurs by providing software and hardware solutions to virtually assist the stables' everyday operations. In this paper, we propose a system that aims to help the Equestrian Federation in Bahrain hold all the things related to endurance races in Bahrain and during international competitions. It consolidates all of the information about the horses, stables, and stakeholders into one system. It centralizes horse, stable, and stakeholder data. A smart wearable horse health monitoring device uses Internet of Things sensors like a heart rate (HR) sensor to assess the horse's HR throughout the race and inform the horse responsible if the horse is in an abnormal condition. The GPS module tracks each horse on a racing track-customized map. Arduino Node-MCU controls GPS and HR and uploads HR and GPS data to the Firebase Database. Horse, race data, and results will be stored in a Firebase real-time database and accessible via a Flutter-developed mobile app. The device stores the QR code affixed by the federation to each horse's passport for identification purposes, thereby facilitating the digital identification of horses. The system will improve endurance race quality quickly by simplifying registration, tracking horse health, and reducing human work.

Keywords: Digital Transformation, Horse, Internet of Things (IoT), Smart horse race, wireless sensor networks (WSN).

1 Introduction

Internet of Things in Animal Healthcare (IoTAH) affects animal and environmental health. IoTAH collects real-time animal health data and alerts via biosensors and smart device modules. IoTAH tracks body temperature, HR, and animal activity. Specialists can diagnose respiratory diseases early with this huge data [1]. HR is a crucial indicator of a horse's well-being during various stages of exercise. Racehorse trainers use HR data to assess fitness, responsiveness to physical exertion, training recovery, and performance potential [2]**[4]**. IoTAH's horse health monitoring and registration systems have revolutionized thoroughbred management, care, and welfare. Healthcare is needed as equine care costs rise. IoTAH successfully manages horses, saves operational expenses, and enhances animal data accuracy. This research intends to design a cost-effective, intelligent, plug-and-play horse health tracking system using sensors. Current monitoring systems lack real-time data collection and processing, limiting their ability to improve training regimens and horse welfare during contests. Thus, a reliable and effective system for recording and analyzing vital signals like HR during contests and offering stakeholders a user-friendly registration process and other value- added services is needed. Stable owners can log in with their phone numbers as identifier with one-time-password (OTP) to access their horse records and information. The Equestrian Federation sends stable owners real-time notifications through the system. The horse's HR and location are tracked by this paper's prototype. This smart device can be attached to the horse during the race, and it is connected to Firebase via ESP8266 WIFI module for real-time horse health monitoring which helps trainers and doctors diagnose horse health issues. The admin panel will display horse, rider, contest, result, and registration data from a Laravel-structured database. A Google Dialog flow Chabot [3] answers typical queries in the app.

The rest of this paper is organized as follows: The literature review about systems related to the work presented in this paper is discussed in the second section. Section 3 explains the methodology of the system's model and the proposed system. In Section 4, the results are discussed and analyzed. Finally, the conclusion and future enhancements are the subject of the last section.

2 Related Works

Many researchers have been focusing in the last few years on using AI, machine learning, and IoT in agricultural and

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animal healthcare. Animal wearables, computer vision, and other sensors evaluate animal health in real-time. Intelligent animal health monitoring has improved technologically, currently, intelligence IoT systems are widely used to monitor and evaluate cattle welfare, productivity, and other factors to be aligned with Sustainable Development Goals (SDGs), i.e., no poverty (SDG 1), zero hunger (SDG 2), and sustainable cities (SDG 11) [4]-[5].

The equestrian industry has grown, and technology to improve horse racing, and training has become more popular, one of the important things is to be aware of the horse's health conditions by keeping track of HR and Harte Rate Variability (HRV) [6] which is a useful sign of changes in the autonomic nervous system's inputs to the heart. HRV refers to the variance in the time intervals between consecutive heartbeats [7]. Thus, monitoring a horse's HR can detect abnormalities early and prevent them from escalating. Following the horse across the 120-kilometer endurance racecourse races becomes unnecessary by attaching a wearable device with a GPS module to the horse. Janzekovic et al. [8] connected horse stress to HR. If HR changes too much, the horse may become weary, dehydrated, or unwell. Monitoring HR and other vital signs helps trainers and vets address issues and prepare the horse for future races. To balance sport and welfare, horse racing stress must be scientifically understood.

The purpose of the research of Witkowska-Piłaszewicz et al. [9] was to ascertain how physical exercise intensity and type affected the level of cortisol in peripheral blood. This long-term research included 21 racehorses, 9 endurance horses, and 30 untrained Arabian horses. Blood samples from racing horses were analyzed every three weeks after four training sessions and two races and from endurance horses every month following two training sessions and one competition. The cortisol concentration is measured before and 30 minutes after physical exertion. This research showed that after both training and competition, cortisol levels increased significantly. However, the rise was more pronounced after competition in both racing and endurance horses.

Wearable technology is a recently emerged trend within the realm of equestrian sports, serving to facilitate the analysis of biomechanics, cardiovascular health, respiratory function, and thermometry-based biometric investigations. This research trend has the potential to contribute to the development of health indicators that may aid in the prevention of heat stress, musculoskeletal injuries, and catastrophic events in horses throughout their athletic lifespan [10]. These devices are functional, but further research and validation are required to address their limitations and optimize their use in various equine activities.

The review paper [11] explores the emerging market of biosensors in animal health management, highlighting various sensor technologies at different stages of commercialization. It emphasizes the adaptation of human-oriented diagnostic technologies for animals and discusses the need for integrating diverse sensors into an efficient online monitoring system. The paper aims to provide comprehensive insights into wearable technologies, nano biosensors, and advanced molecular biology techniques for detecting infectious diseases in animals, advocating for their integration to enhance future animal welfare.

Kandepan and Venkatesan [12] introduces a novel methodology that leverages Wireless Sensor Networks (WSN) and Internet of Things (IoT) technology to enable the continuous monitoring of animal health. The Animals Smart Healthcare Monitoring (ASHM) system utilizes sensors to monitor physiological parameters such as temperature, heart rate, and ECG. This system provides a high level of precision in monitoring animal behavior and health. It achieves a reduction in latency of 75% and maintains an impressive output accuracy of 98%.

A study by Furtado and Trobec [13] examines various medical fields with potential chances to employ WSN to enhance the management of medical resources, to aid medical personnel, or to provide improved and cost-effective personal health. The hardware components of the prototype presented in the paper [13] incorporate several cutting-edge technologies. Specifically, a microcontroller as the central processing unit, while a GPS sensor module and a heartbeat sensor were also included. By incorporating the hardware components, the prototype is able to deliver a high level of performance and functionality, paving the way for even more innovative designs and features in future iterations.

J. Veintimilla et al. [14] describes the creation of a cattle tracking device to measure the temperature and geolocation of the cattle using a GPS receiver module and IoT technology. The system is made up of a GPS receiver, WiFi, and various sensors, including an accelerometer and temperature sensor. The wireless tracking module proposed in this paper can offer a framework for a large-scale tracking system that could be used to track the geolocation and health condition of cattle.

R. Brugarolas et al. [15] proposed a Wearable HR Sensor System to detect and monitor Canine Health, this project used an electrocardiogram (ECG), photoplethysmogram (PPG), and inertial measurement units (IMU) to remotely and continuously monitor the vital signs of dogs. The IMU sensor is used to monitor the dog's behaviors. Maximilian Treiber et al. [16] compiles an overview of IoT horse health sensor systems available in Germany and deployed on horses, stables, and pastures. The review identified three types of sensors that can be attached to the horses, such as motion sensors, rug sensors, and health monitoring sensors. The research also identifies the deployment options for the heart rate sensor and health monitoring systems to help to detect colic in horses.

The study in [17] compares the accuracy of HR and HRV readings during high-intensity exercise using an integrated horse fitness tracker called Equimetre (Arioneo, Paris, France) and a telemetric ECG device (Televet, Jørgen Kruuse, Denmark). Equimetre (https://training.arioneo.com/en/arioneo-home/), despite being scientifically validated for measuring HR and HRV, requires data correction and validation at higher exercise intensities. Equimetre HR and Televet HR correlated well for HRV parameters when corrected. The Equimetre was validated for horse HR monitoring during high- intensity exercise and produced reliable HRV values using corrected ECG data. Hylofit (https://hypostore.com/hylofit-heart-rate-monitor. html), a horse-specific wearable device, tracks HR, mobility, and other vital signs in real-time for riders, trainers, and vets. The device helps riders and trainers evaluate their horses' fitness, training load, recovery, and health. Hylofit monitors horse performance via a girth sensor and smartphone app.

Kapteijn et al. [18] used two sensors, Fig. 1(a) shows how to reliably monitor horse heartbeats with the Televet electrode (red, black, yellow, and green dots) and hylofit sensor (dark blue band). Hylofit tracks horses during training but not racing. Ekuore (https://www.etrakka.com.au/), despite exhibiting agreement with gold standard reference ECGs at rest, lacks validation for different gaits, and its clip-style application may not be appropriate for racing. E-Trakka provides comprehensive fitness analytics, but validation for maximal efforts such as racing is absent. Equinity (https://equinitytechnology.com) provides a variety of biometric measurements but does not detect cardiovascular anomalies automatically. Motion Sport's (https://equisense.com/) real-time data analysis is limited and may not effectively detect cardiorespira- tory anomalies. Stridemaster (https://www.stridemaster.com) shows promise in predicting musculoskeletal injuries, but it does not measure other biometrics such as HR or body temperature.

The proposed system in this paper integrates IoT devices with real-time horse health monitoring, race registration, news, and results in one application.

3 Proposed System

This part introduces our smart horse health monitoring system. The technology measures horse HR, temperature, and location and sends the data to Firebase, a cloud-based real-time database. This allows horse owners, veterinarians, and trainers to easily access health information through a Flutter mobile app, enabling prompt and educated animal care decisions. The system uses Flutter, Laravel, and Firebase. The mobile app communicates with Firebase to collect sensors' data, allowing real-time horse performance monitoring during races. Started with the health monitoring device which has been constructed for horses, incorporating body area sensors, temperature, and HR monitors, and a GPS module for precise horse location tracking. The hardware device was mounted on horse breast.

Fig. 1(b) shows the proposed system approach where equine vital health and location are determined and sent to Firebase using a Microcontroller coupled to sensors. Fig. 1(c) shows the black diagram of the device. Its primary function is to measure and record various horse data during races, ensuring that critical parameters remain within safe limits to preserve the horse's health and monitor its performance before and after each race. The collected horse data is then transmitted to a Real-Time Database, constantly updating the information. Fig. 1(d) illustrates the temperature sensor, GPS module, and HR sensor interfacing Node-MCU designed on 'Fritzing' software. The MLX90614 sensor VIN and GND pins are connected to the Node-MCU VIN and GND pins, respectively. The Node- MCU's D1 and D2 pins are connected, respectively, to SCL and SDA. Connecting the Neo-6m GPS module's VCC and GND pins to the Node-MCU's VE and GND pins, respectively. The GPS TX pin is connected to the Node-MCU TX pin for data transmission. The Node-MCU sends sensor data to Firebase via 8266 WIFI module, and if horse HR values or location outside the track are irregular (exceed the threshold values), the horse owner and trainer receive push notifications. HR is a reliable indicator of a horse's condition before, during, and after exercise. The proposed system calculates the Horse Motion Index HMI (See equation (2)) taking into account the different phases of horse activity: standing, walking, jogging, trotting, and Galloping. The measured values are normalized by using the min-max normalization (See equation (1)).

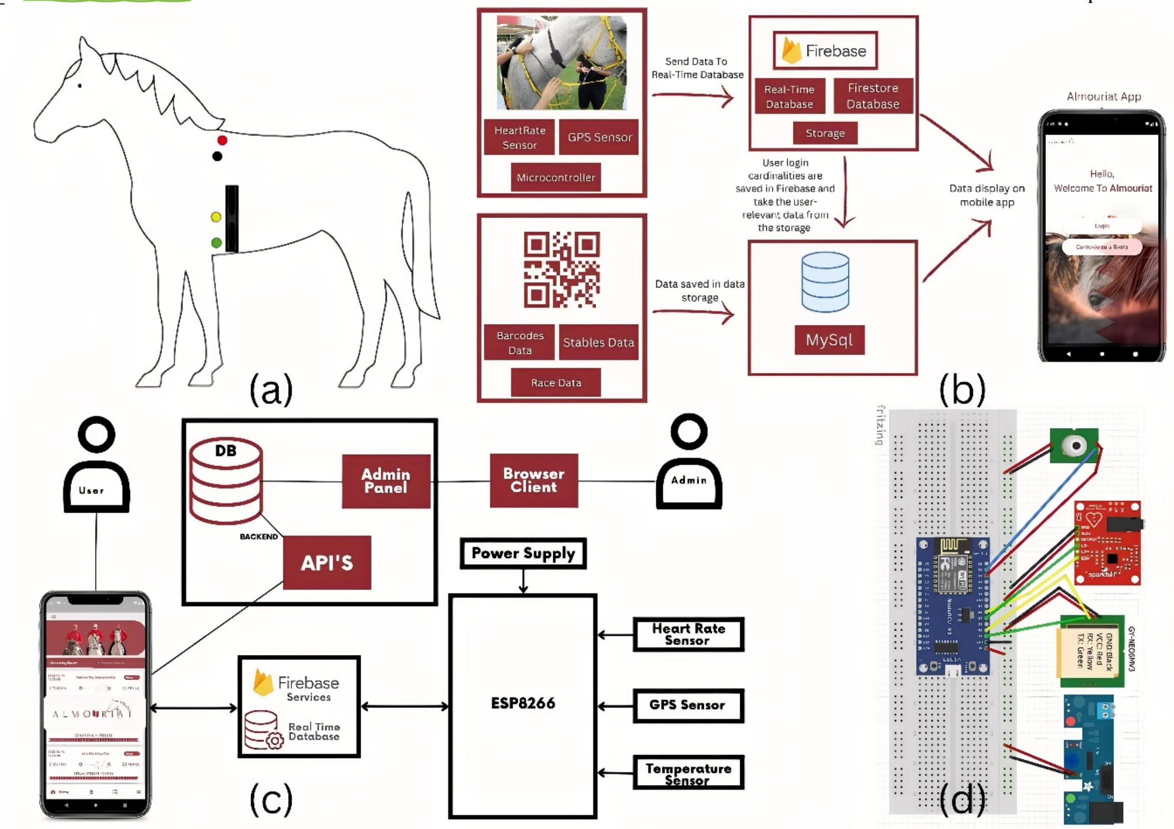

Fig. 1: (a) Graphic representation of the placement of the HR sensors. (b) The Proposed System Approach. (c) Block diagram of the smart device sensors. (d) Interfacing Node-MCU with sensors in ’Fritzing’ software.

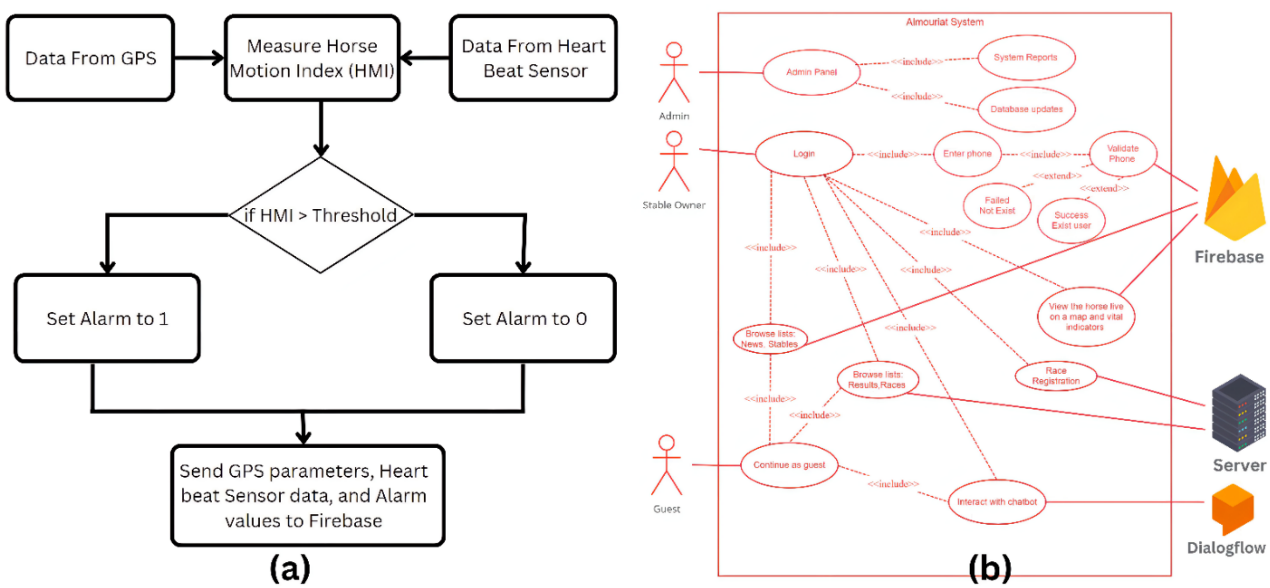

Fig. 2: (a) Arduino code flowchart. (b) System Use Case Diagram.

The resting HR for a mature horse is 30-40 beats per minute, while the maximum HR ranges from 220-260 beats per minute. To achieve optimal aerobic fitness, the HR should be sustained between 100-165 beats per minute. A recovery HR of around 100 beats per minute within two minutes indicates good anaerobic condition. After exercise, the HR should drop below 60 beats per minute after 10 minutes. Continuous monitoring is necessary if the HR remains elevated, as it may indicate fatigue. The threshold value for the normalized Horse Monitoring Index (HMI) is established as either 1 or -1. If the calculated HMI surpasses this threshold within a specified time range, the alarm value is set to 1. This serves to inform the horse owner and trainer regarding a specific horse’s health status or to indicate that the horse has deviated from the track.

Min-max normalization, also known as feature scaling or rescaling, is a data preprocessing technique used to transform numerical data into a common scale. It involves scaling the data to a specific range, typically between 0 and 1, based on the minimum and maximum values of the dataset.

Algorithm 1: Smart Sensor Data Collection

Result: Send measured data to Firebase Initialization;

while *True* **do**

heart Rate = Read heart rate from the sensor

gps Coordinates = Read GPS coordinates from the sensor

temperature = Read temperature from the sensor

speed = Read speed from the sensor time = Read time from the sensor

Z=Normalized values of the sensor's readings using equation (1)

hmi = Perform calculations to determine the HMI using equation (2)

if *hmi > threshold* **then**

alarmValue = 1

else

alarmValue = 0

end

data = { "heartRate": heartRate, "gpsCoordinates": gpsCoordinates,

"temperature": temperature, "speed": speed,

"time": time, "hmi": hmi, "alarmValue": alarmValue

};

Send data to Firebase; Delay for a certain interval;

End

Fig. 2 (a) shows the flowchart diagram of the proposed system. The flowchart highlights the main stages of the program starting from collecting from sensors and GPS the measured real-time horse health data such as HR, temperature, and GPS coordinates. The measured data are normalized, and HMI is calculated based on the normalized measures. If the HMI exceeds the accepted limits, which are fixed according to the horse's activity: standing, walking, jogging, trotting, and Galloping, the system sends a notification to the horse owner and trainer to take necessary action.

The formula for min-max normalization used in this research is as follows:

$$Z = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Where Z is the newly computed value, X is the original value, Xmin is the minimum attribute value, Xmax is the maximum attribute value.

The Horse Motion Index (HMI) is a metric used to assess the quality and smoothness of a horse's motion during various gaits, such as walking, trotting, and cantering. The HMI is calculated by analyzing the speed and health measurement patterns of the horse using the GPS sensor to measure the speed and heart rate sensor to measure the temperature and heart beats using sensors attached to the horse's body.

$$Horse\ Motion\ Index\ (HMI) = \frac{\sum_{i=1}^{N}\left[\sum_{j=1}^{4} w_j\, z_j + \sum_{k=1}^{2} w_k\, z_k\right]_i}{\sum_{i=1}^{N}\left[\sum_{j=1}^{4} w_j + \sum_{k=1}^{2} w_k\right]_i} \quad (2)$$

While i corresponds to the N sensor nodes connected to N the horse, j corresponds to the four parameters from GPS sensor. W_1, W_2, W_3, and W_4, are the weights corresponding to latitude and longitude, speed, and time. k corresponds to the temperature and HR parameters from the HR sensor.

Fig. 2(b) shows the use case diagram of the software part the main actors are on the left, the objectives are in the middle, and the supporting actors are on the right, which is in our case the servers. The main actors are using the system to achieve their objectives. The system uses supporting actors to help the main actors achieve their objectives. The diagram illustrates that there are three main actors in our system. The administrator has access to control over the application's backend data. The second is the stable owners, who can register the horse for endurance races and track their horse's health and location. The third is the guest since it is expected that horse enthusiasts will use the app as guests to follow all the news and updates. As an example, all users can access news, race data, and Chabot. The diagram also illustrates our three support actors: our database server, Firebase, and Dialog Flow, a Google AI platform utilized by Chabot to interact with users. The app splits the frontend and backend. This separation can protect sensitive data and business logic from unauthorized access using the Flutter mobile app. The backend can be hosted on a secure server and only expose a limited number of API endpoints to the frontend, reducing the risk of data breaches or unauthorized access to important information. Improved scalability allows the backend to handle more API queries without compromising the frontend. New frontend features or adjustments can be made without affecting the backend. The program may be instantly deployed on any server or host, helping us construct a cost- effective system. The Flutter app functions as a native app and the microcontroller and sensors are affordable, so the suggested system can create a cost-effective solution with good performance.

4 Results and Discussion

The software and hardware components have been integrated and tested on a horse, proving the system's concept and paving the way for low-cost, more advanced systems to improve endurance race quality and horse health. Kapteijn et al. [18] ECG electrode placements were used in our project (Fig. 4(b)).

Fig. 3 illustrates the measured BPM and speed during a 30-minute test conducted on the racetrack at various activity stages: walking, jogging, trotting, and galloping. The figure also displays the calculated normalized HMI using equations (1) and (2). The results indicate normal health behavior, as the HMI did not exceed 1, which is the designated threshold for an alert status.

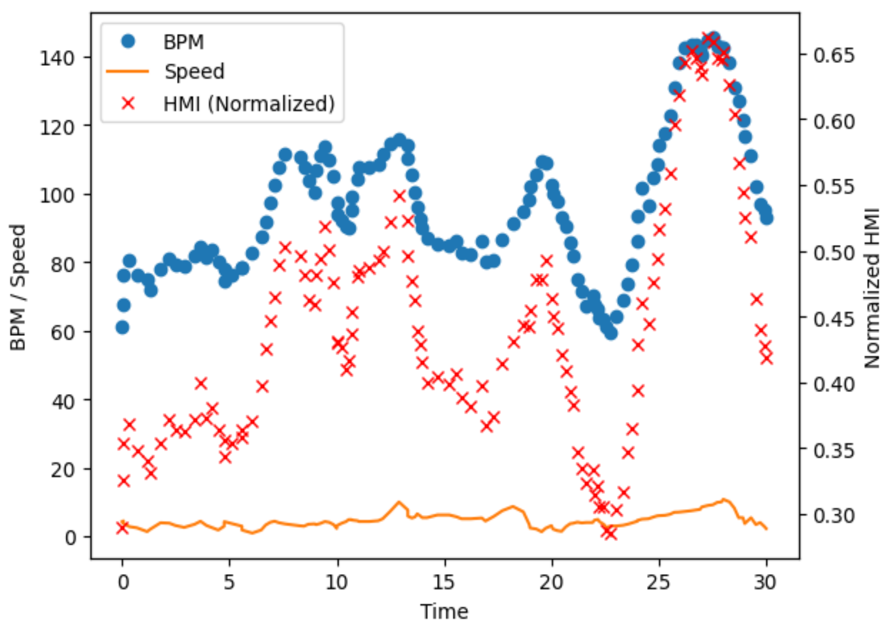

Fig. 3: Measured Heart Rate, Horse Motion Index and speed

Fig. 4(a) shows the Bahrain endurance racetrack race with horses represented by latitude and longitude data from sensors. To identify whether the horse is inside or outside the race boundaries, this depiction is updated constantly. The figure also shows checkpoints that may be customized for each race event and notify owners when the horse passes them. Fig. 4(c) shows that the proposed prototype is properly connected and linked to the Firebase real-time database, which receives GPS longitude and latitude values, and that the app is integrated with Google Map API, which uses Firebase data to display horse locations on a custom map and determine if the horse is inside or outside the racetrack. Fig. 4(d) shows the horse's HR and speed values to help owners monitor its health during the endurance event. Each horse passport gets a barcode sticker for endurance race registration. Which can simplify endurance horse registration. In horse endurance competitions, barcodes can save the horse's passport number and obtain its name, vaccine, age, and other data from the database.

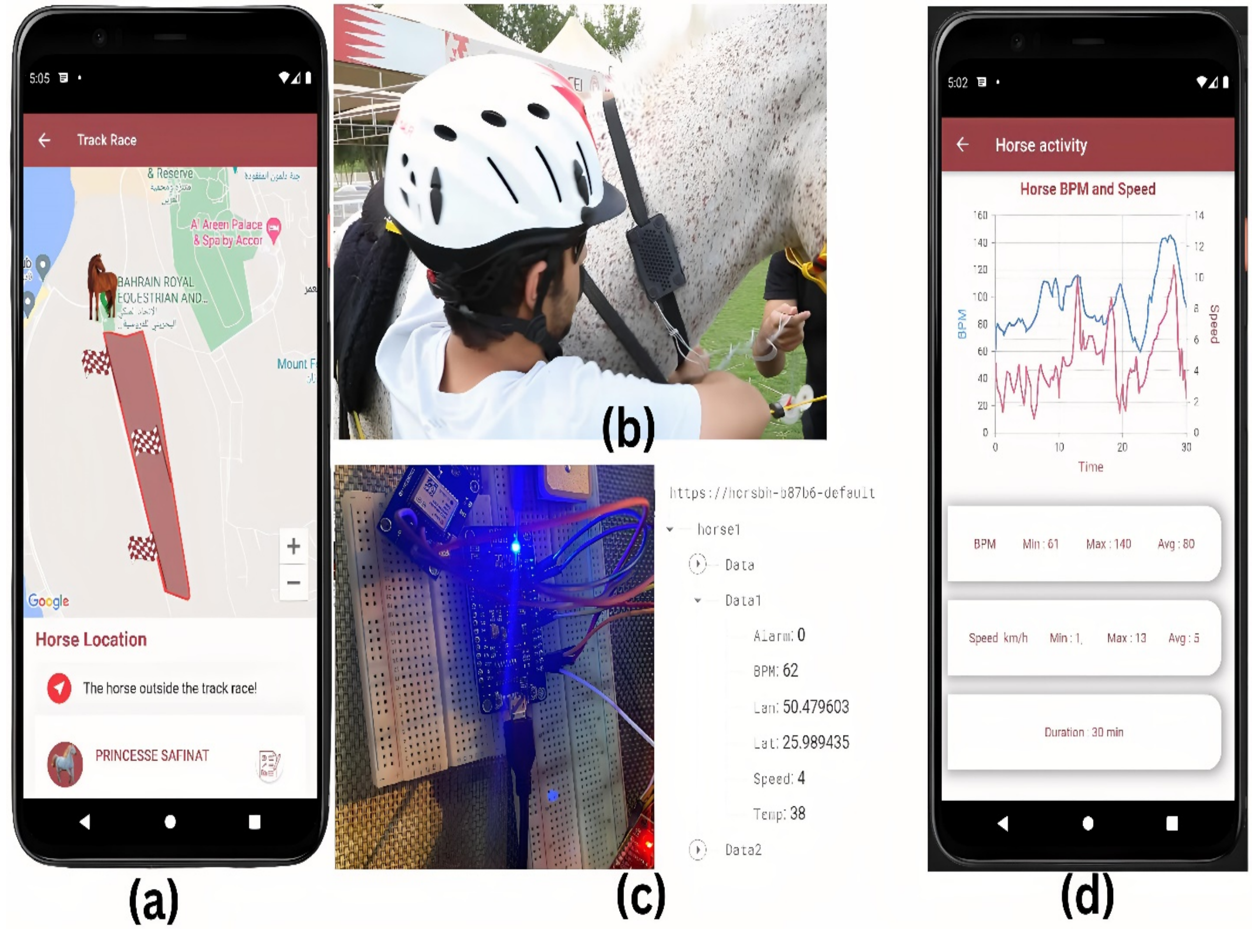

Fig. 4: (a) Application screenshot of the location of the horse during the testing. (b) The placement of the hardware circuit on the horse. (c) Hardware circuit and Firebase received measures. (d) Application screenshot of the horse's Heartbeats and speed measurements over 30 minutes.

Table 1 summarizes the available commercial wearable devices in the market for biometric monitoring of horse health and the comparison of these devices with our proposed system.

Table 1: Summary of comparing available commercial technologies with our work

Devices	**HR**	**HRV**	**Temperature**	**GPS**	**Speed**	**Wearable**	**Wireless**	**Remote Monitoring**	**Real-time Measurement**
Equimetre	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Motion Sport	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes
E-trakka	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Hylofit	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes
EKuore	Yes	Yes	No	No	No	No	No	Yes (via Bluetooth)	Yes
our work	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

As shown in Fig. 5(a), scanning the information from the app into a registration system improves accuracy and timeliness. Fig. 5(b) shows the Chabot page added to the system, which lists the benefits of using a Dialog flow-powered Chabot for endurance race news in a mobile app. For instance, can allow users to ask questions or seek race or rider details. This makes tracking the race more customized and engaging, answers questions quickly, saves time, and simplifies communication.

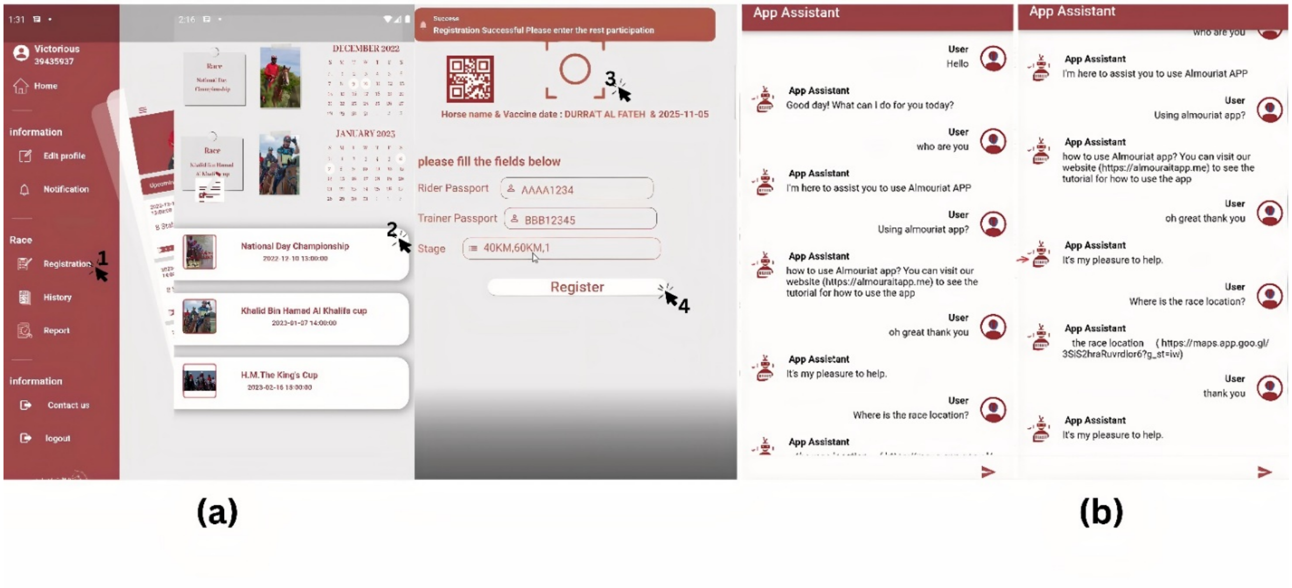

Fig. 5: (a) Registration page for the race. (b) Integrating Chabot in the mobile application

After implementing the application and connecting it to the backend, data retrieval from Firebase and the server became a smooth process. The registration page shows in **Fig. 6** also allowed for seamless data posting to the server. Additionally, testing of the application revealed that the project objectives have been successfully achieved and communication with all stakeholders has been significantly simplified. The use of the latest technologies and best practices throughout the development process has enabled us to deliver high-quality and user-friendly applications. Furthermore, the application architecture is designed in a way that makes it easy to maintain, scale, and add new features in the future.

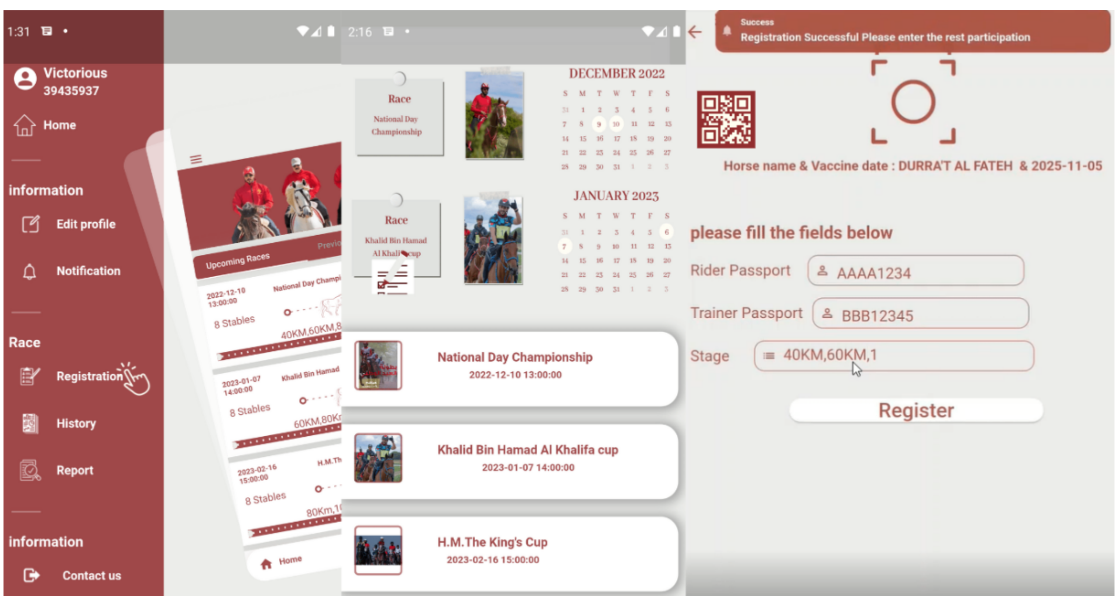

Fig. 6: The registration pages

5 Conclusion

The developed system holds significant importance for horse establishments and stable owners, providing an innovative solution to the challenges they face. This paper offers a comprehensive overview of Horse health and management IoT systems, the proposed system, and the studies utilized in its development, which will continue to inform future research. The system's design incorporates the latest technologies and best practices to ensure high-quality performance, user-friendliness, and efficiency. Furthermore, the architecture is designed with scalability and ease of maintenance in mind, enabling future expansion and feature addition. The almouriat system was developed to meet the unique needs of horse owners in the Kingdom of Bahrain, specifically monitoring their horses' health and readiness for races. Using IoT devices, the system allows for real-time monitoring of vital signs and simplifies many procedures for horse owners.

Conflicts of Interest

The authors declare that there is no conflict regarding the publication of this paper.

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