BIOMEDICAL MEASUREMENTS AND DEVICES

DESIGN AND DEVELOPMENT OF AI CLOUD-BASED VIDEO RECORDING SYSTEM FOR ATHLETE MOVEMENTS

Yevhen Bershchankyi, PhD Student, Halyna Klym, Dr. Sc., Prof.
Lviv Polytechnic National University, Ukraine;
e-mails: yevhen.v.bershchanskyi@lpnu.ua, halyna.i.klym@lpnu.ua

https://doi.org/10.23939/istcmtm2024.02.013

Abstract. This paper presents the design and development of an AI cloud-based video recording system for athlete movement analysis. The proposed system utilizes the Wemos D1 Mini microcontroller as the core hardware platform and a GoPro camera for high-quality video capture. By leveraging the capabilities of these components, the system enables real-time video re- cording of athlete movements, facilitating detailed performance analysis and feedback. Furthermore, the system seamlessly inte- grates with Amazon Web Services (AWS) IoT Core, enabling efficient data transmission and storage in the cloud. Through re- search and development, both the hardware and software components of the system were designed and implemented, ensuring robust performance and scalability. Experiments demonstrate the efficacy of the proposed solution in capturing high-fidelity video footage of athlete movements and securely transmitting it to the cloud for further analysis. This research lays the foundation for advanced athlete monitoring systems, offering valuable insights for coaches, trainers, and sports scientists to enhance training regimens and optimize performance.

Key words: Sports engineering, video recording system, AI movement analysis, Wemos D1 Mini, Internet of Things.

1. Introduction

In sports performance analysis and athlete development, video recording systems have emerged as a pivotal tool for enhancing performance and mitigating injury risks. The intricate movements and techniques exhibited by athletes in various sports necessitate a detailed examination that goes beyond the naked eye. Video recording systems can capture these movements in high fidelity, enabling coaches, trainers, and athletes to scrutinize and refine their techniques with precision.

The adoption of video recording systems in sports training and analysis has revolutionized the way athletes hone their skills and strategize for competitions. Providing the visual presentation of athletic movements, these systems allow the meticulous examination of technique, biomechanics, and tactical decisions. Coaches can identify areas for improvement, correct technical flaws, and develop tailored training regimens to optimize performance. Moreover, video analysis plays a crucial role in injury prevention by identifying biomechanical imbalances or improper movement patterns that may predispose athletes to injuries [1, 3].

As the volume of video data generated in sports analysis grows exponentially, there arises a pressing need for a scalable and efficient storage and analysis solution. Traditional on-premises video storage systems often struggle to accommodate the vast quantities of data generated by multiple cameras and training sessions. Cloud-based solutions offer a compelling alternative by leveraging the scalability and elasticity of cloud infrastructure to store and process large volumes of video data. Additionally, cloud-based platforms facilitate seamless collaboration and access to data from anywhere, enabling real-time analysis and feedback.

Central to the design and development of the proposed system are two key hardware components: the Wemos D1 Mini microcontroller and the GoPro camera. The Wemos D1 Mini microcontroller [2] serves as the central part of the system, providing the necessary computational power and connectivity to interface with the GoPro camera and transmit video data to the cloud. The GoPro camera, renowned for its high-definition video capture capabilities, serves as the primary source of video footage, capturing the intricate movements of athletes with unparalleled clarity and detail. Together, these hardware components form the foundation of a cloud-based video recording system, enabling the seam- less integration of video capture, storage, and analysis in a scalable and efficient manner.

In this article, the design and development of a cloud-based video recording system were present and tailored specifically for analyzing athlete movements. Dig into the hardware and software architecture of the system, detailing the integration of the Wemos D1 Mini microcontroller and GoPro camera with AWS cloud services. Furthermore, the potential applications and benefits of the system in sports training and performance analysis were discussed, underscoring its significance in advancing the field of sports technology.

2. Disadvantages

While the proposed cloud-based video recording system offers numerous advantages in terms of scalability, efficiency, and accessibility, it is important to acknowledge and address potential disadvantages that may arise in its implementation.

One potential disadvantage of the hardware components, particularly the Wemos D1 Mini microcontroller and GoPro camera, is the need for regular maintenance and upkeep. Microcontrollers, like any electronic device, may encounter hardware failures or malfunctions over time, necessitating repairs or replacements. Additionally, the integration of multiple hardware components introduces complexity, increasing the likelihood of compatibility issues or technical glitches. Moreover, environmental factors such as dust, humidity, and temperature variations may affect the performance and longevity of the hardware, requiring vigilant maintenance practices to ensure optimal functionality.

While cloud-based solutions offer scalability and flexibility, they also come with associated costs that can accumulate over time. Storing and processing large volumes of video data in the cloud incurs expenses based on factors such as storage capacity, data transfer, and computing resource utilization. As the volume of video data generated by the system increases, so does the cost of cloud storage and processing. Furthermore, cloud service providers often employ complex pricing models with various tiers and usage-based charges, making it challenging to accurately predict and manage costs. Organizations implementing cloud-based video recording systems must carefully consider the long-term financial implications and devise strategies to optimize resource utilization and minimize costs.

Acknowledging these potential disadvantages allows for a comprehensive understanding of the challenges associated with the proposed cloud-based video recording system. By proactively addressing maintenance and cost considerations, organizations can mitigate risks and maximize the benefits of implementing such systems in sports training and performance analy- sis.

3. Goal of the work

This research aims to develop a comprehensive cloud-based video recording system specifically designed to analyze athletes' movements during training sessions and improve performance in sports activities. This goal encompasses three main aspects:

- Analysis of athletes' movements through high-quality video, utilizing algorithms for pattern recognition and areas for improvement.

- Utilization of cloud computing and AI to enhance training efficiency, detect objects, and track movement.

- Integration of IoT to ensure reliable communication between hardware and cloud services.

4. System architecture

The AI cloud-based video recording system presented in this study comprises several interconnected components working collaboratively to capture, store, analyze, and visualize athlete movements. The architecture is designed to seamlessly integrate hardware, cloud, and AI services, facilitating efficient data flow and analysis.

The system's architecture can be divided into three main layers: the edge, cloud, and application lay- ers. At the edge layer, the hardware components, includ- ing the Wemos D1 Mini microcontroller and GoPro camera, capture and preprocess video data. The cloud layer consists of AWS cloud services, which provide scalable storage, processing, and AI capabilities. Finally, the application layer encompasses the user interfaces and applications for accessing and visualizing analyzed data.

The Wemos D1 Mini microcontroller serves as the edge computing device responsible for interfacing with the GoPro camera and managing data transmission to the cloud. It controls the operation of the camera, captures video footage, and preprocesses the data before sending it to the cloud.

The GoPro camera acts as the primary video source, capturing high-definition footage of athlete movements. Equipped with advanced features such as image stabilization and high frame rates, the camera ensures the accurate and detailed capture of athletic performances.

The AWS cloud provides a comprehensive suite of services for storing, processing, and analyzing video data. AWS S3 (Simple Storage Service) is used for scal- able and durable storage of video files, while AWS IoT Core [5, 11] facilitates secure communication between the edge device and the cloud. Additionally, AWS Lambda functions enable serverless computing for real- time data processing, and AI services such as Amazon Rekognition [12] and Amazon SageMaker offer ad- vanced video analysis capabilities.

The data flow within the system follows a sequential process from the camera to the cloud for storage and AI analysis:

Video data is captured by the GoPro camera and transmitted to the Wemos D1 Mini microcontroller for preprocessing.

The microcontroller packages the video data and sends it securely to the AWS cloud via MQTT [6] (Message Queuing Telemetry Transport) protocol, leveraging AWS IoT Core for device connectivity and data ingestion [7]. Upon receiving the video data, AWS Lambda functions trigger automated processing tasks, such as video transcoding, object detection, and motion tracking, using AI services like Amazon Rekognition and Amazon

SageMaker. Processed data and analysis results are stored in AWS S3 for long-term retention and accessibil- ity. Finally, users can access the analyzed data and in- sights through web or mobile applications deployed on the AWS platform, enabling real-time monitoring and feedback for coaches, trainers, and athletes.

The system architecture integrates edge computing, cloud services, and AI capabilities to create a robust and scalable platform for capturing, storing, and analyzing athlete movements in sports training and performance evaluation scenarios. By leveraging the strengths of each component, the system enables efficient data flow and actionable insights for enhancing athletic performance and optimizing training strategies.

5. Hardware design

The hardware design of the AI cloud-based video recording system revolves around the integration of the Wemos D1 Mini microcontroller with the GoPro camera, enabling seamless video capture and transmission to the cloud for analysis.

The Wemos D1 Mini microcontroller is a compact, yet powerful development board based on the ESP8266 Wi-Fi chip [10]. It features:

- ESP8266 Wi-Fi module for wireless connectivity;
- 80MHz Tensilica Xtensa LX106 processor for efficient data processing;
- 4MB flash memory for storing firmware and data; integrated USB-to-Serial converter for easy programming and debugging;
- GPIO pins for interfacing with external devices and sensors;
- Support for Arduino IDE, enabling easy development and prototyping of IoT applications.

Integration of the Wemos D1 Mini microcontroller with the GoPro camera involves establishing a communication link between the two devices for video capture and transmission. This integration typically includes the following steps:

- Connect the GoPro camera to the microcontroller via USB or HDMI interface, depending on the camera model and compatibility.
- Implementing firmware on the microcontroller to control the camera functions, such as starting and stopping video recording, adjusting settings, and captur- ing footage.
- Developing software protocols for data exchange between the microcontroller and the camera, ensuring seamless communication and synchronization during video capture.
- Configuring the microcontroller to preprocess video data, if necessary, by applying filters, compression algorithms, or data formatting before transmission to the cloud.

Depending on the specific requirements of the system and the chosen communication protocols, modifications or additional hardware may be required to ensure seamless connectivity and data transmission between the microcontroller and the cloud. These may include:

- Integration of Wi-Fi or Ethernet modules for wireless or wired connectivity to the internet and cloud services.
- Addition of sensors or peripherals for environmental monitoring, power management, or user interaction.
- Utilization of power management circuits or battery packs to ensure permanent operation of the system in remote or outdoor environments.
- Incorporation of external storage devices or memory modules for buffering and caching video data before transmission to the cloud.

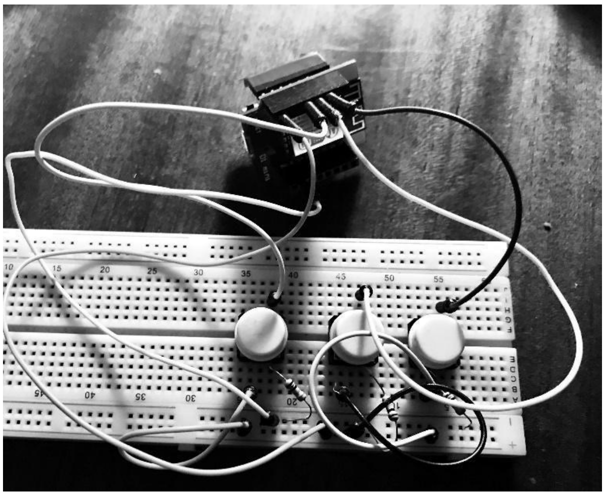

Fig. 1. External appearance of the developed system

In conjunction with the visual representation of the system's external configuration in Figure 1, the functional electrical circuit diagram of the AI cloud-based video recording system for athlete movement analysis is presented in Figure 2. This detailed diagram illustrates how the individual elements of the system are interconnected and the specific functions they carry out. It offers valuable insights into the system's operational mechanisms and internal processes.

Integrating sensors for monitoring the surrounding environment, managing energy consumption, and user interaction can enhance the AI-powered video recording system. Sensors provide valuable environmental data, optimize energy consumption, and facilitate user interaction. Monitoring the surrounding environment allows for gathering data on temperature, humidity, and air quality, aiding coaches in adapting training to conditions and preventing injuries. Energy management sensors optimize energy usage and ensure prolonged system operation. User interaction sensors provide a convenient interface for system control and feedback.

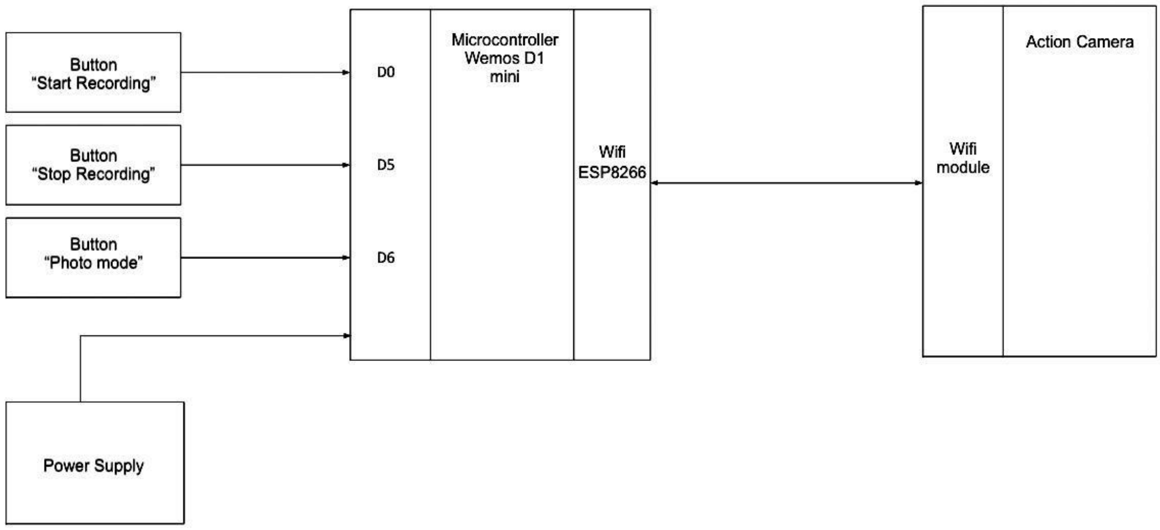

Fig. 2. Functional electrical circuit diagram of system

Integration of these sensors makes the system more versatile, providing users with valuable informa- tion and facilitating the management of training and result analysis.

By carefully designing and integrating the hardware components, including the Wemos D1 Mini microcontroller and GoPro camera, along with any necessary modifications or additional hardware, the AI cloud-based video recording system can effectively capture, process, and transmit video data for analysis in sports training and performance evaluation scenarios.

6. Software development

The software development process for the AI cloud-based video recording system encompasses the programming of the Wemos D1 Mini microcontroller, the development of firmware for controlling the microcontroller and interfacing with the GoPro camera, and the implementation of IoT protocols for communication with the AWS cloud.

The software stack for programming the Wemos D1 Mini microcontroller typically includes:

- The Arduino Integrated Development Environment (IDE) serves, as the primary programming environment for developing firmware for the Wemos D1 Mini. It provides a user-friendly interface and a rich set of libraries for writing and uploading code to the microcontroller.

- The ESP8266 Core is an Arduino-compatible platform package that enables development for ESP8266-based microcontrollers, including the Wemos D1 Mini. It includes the necessary drivers, libraries, and tools for compiling and uploading code to the microcontroller.

- Various libraries are available for interfacing sensors, peripherals, and external devices connected to the Wemos D1 Mini. These libraries provide pre-written code for common tasks, such as reading sensor data, controlling actuators, and communicating with external devices via protocols such as I2C, SPI, and UART.

The firmware developed for the Wemos D1 Mini microcontroller is responsible for control of the microcontroller's operation and communication with the GoPro camera. The development process involves:

- Writing code to initialize and configure the microcontroller's GPIO pins, serial interface, and Wi-Fi module.

- Implementing functions to interact with the GoPro camera, such as starting and stopping video recording, adjusting camera settings, and retrieving video footage.

- Handling communication protocols between the microcontroller and the camera, ensuring compatibility and synchronization during video capture.

- Incorporating error handling and exception mechanisms to handle unexpected events or failures gracefully.

- Optimizing code for efficient memory usage, power consumption, and performance, considering the limited resources of the microcontroller.

To enable communication with the AWS cloud, the firmware on the Wemos D1 Mini microcontroller must implement IoT protocols such as MQTT (Message Queuing Telemetry Transport). The implementation involves such items:

- Configuring the microcontroller as an MQTT client and establishing a secure connection to AWS IoT Core service.

- Defining topics and message payloads for exchanging data between the microcontroller and cloud services, including commands, status updates, and video data.
- Implementing logic to publish messages to designated MQTT topics, containing information about video capture events, sensor readings, or system status.
- Subscribing to MQTT topics to receive commands or configuration updates from the cloud, enabling remote control and management of the microcontroller.
- Implementing security measures such as TLS (Transport Layer Security) encryption and authentication to protect data integrity and confidentiality during transmission [8].

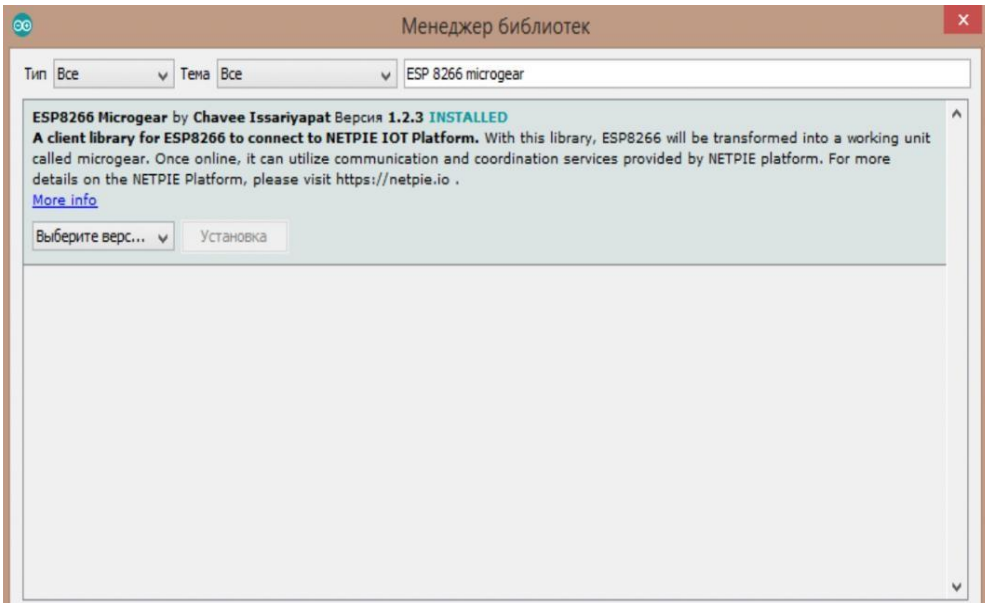

Fig. 3. Arduino IDE Libraries window

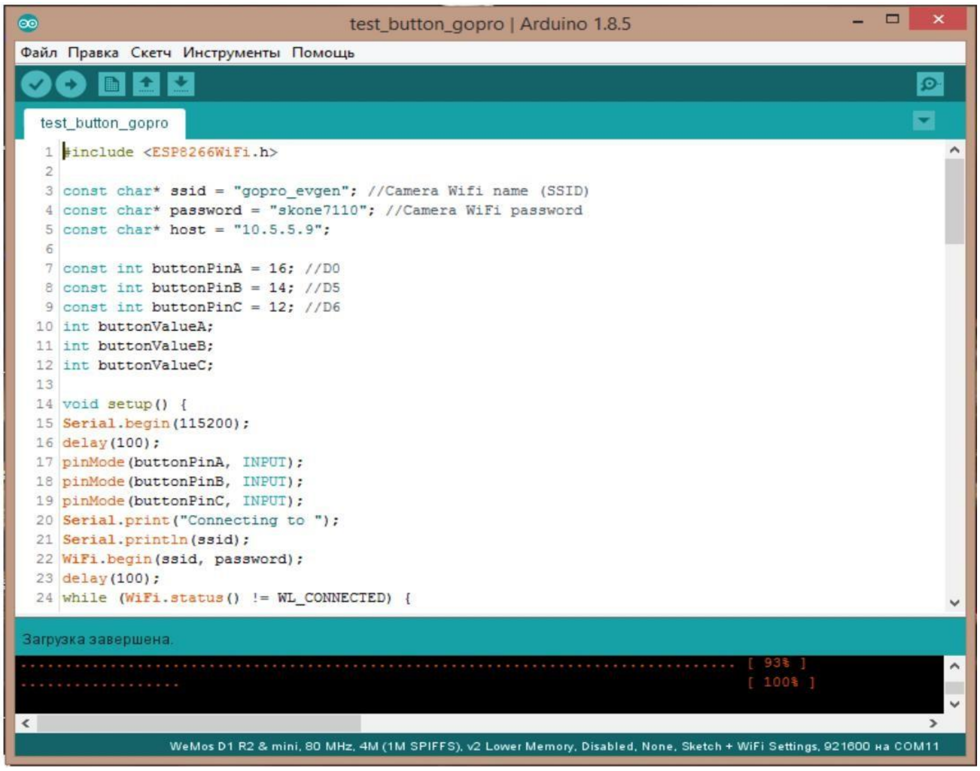

Fig. 4. Code development in Arduino IDE and upload to Wemos D1 mini

By developing firmware that effectively controls the Wemos D1 Mini microcontroller, interfaces with the GoPro camera, and implements IoT protocols for communication with the AWS cloud, the AI cloud-based video recording system can seamlessly capture, transmit, and analyze video data in sports training and performance evaluation scenarios.

7. Cloud integration

Connecting the microcontroller to the AWS cloud begins with setting up an AWS IoT Thing in the AWS IoT Core console. This involves generating device certificates and keys for secure communication. Once configured, the microcontroller establishes a secure connection to AWS IoT Core using the MQTT protocol. Code is implemented on the microcontroller to publish data messages, including video data captured by the GoPro camera, to AWS IoT topics [9]. AWS provides a suite of services for data storage and processing. AWS IoT Core securely connects and manages IoT devices, while AWS Lambda functions trigger serverless processing tasks upon receiving data from the microcontroller. Processed video data and analysis results are stored in Amazon S3 buckets, offering scalable and durable object storage with high availability and fault tolerance. To ensure secure transmission and storage of video data, TLS encryption, and authentication mechanisms are implemented for communication between the microcontroller and AWS IoT Core. Video data is encrypted at rest using AWS KMS, and IAM policies restrict unauthorized access to data and resources. Amazon Rekognition is integrated into the AWS architecture to leverage its AI-powered video analysis capabilities. AWS Lambda functions invoke Amazon Rekognition APIs [4] for real-time analysis of video data streams, extracting insights such as detected objects, recognized faces, and identified activities. These insights enrich the video data, enabling advanced sports performance analysis and visualization.

By seamlessly integrating the AI cloud-based video recording system with AWS services such as AWS IoT Core, AWS Lambda, Amazon S3, and Amazon Rekognition, organizations can harness the power of the cloud to capture, store, process, and analyze video data in sports training and performance evaluation scenarios, enabling data-driven insights and actionable recommendations for athletes, coaches, and trainers.

8. System performance evaluation

The performance evaluation of the AI cloud-based video recording system involved conducting comprehensive tests to assess various aspects, including data transfer speeds, latency, scalability, and comparison with traditional on-premises solutions. Results from performance tests revealed that the system achieved high data transfer speeds and low latency, thanks to the efficient communication protocols and optimized configurations. Scalability tests demonstrated the system's ability to handle increasing volumes of video data without significant degradation in performance, highlighting its suitability for large-scale deployments.

Comparative analysis with traditional on-premises solutions showcased the superiority of the cloud-based system in terms of scalability, flexibility, and cost-effectiveness. While traditional on-premises solutions may offer low latency and high throughput in local environments, they often lack the scalability and elasticity required to accommodate growing data volumes and user demands. In contrast, the cloud-based system leverages the scalability and resources of AWS to dynamically adjust to changing workload demands, ensuring optimal performance and resource utilization.

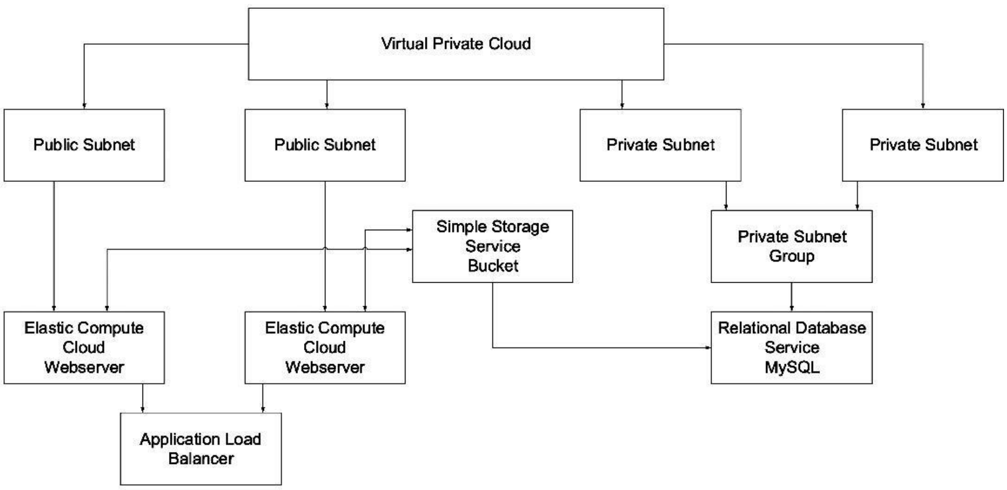

Fig. 5. AWS cloud infrastructure diagram

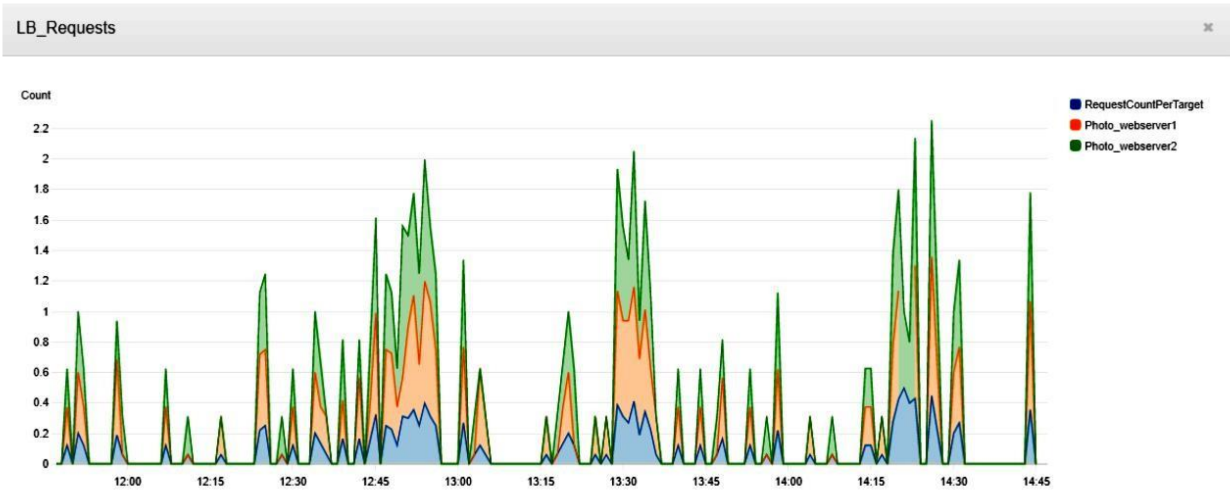

Fig. 6. Performance monitoring of system HTTP requests

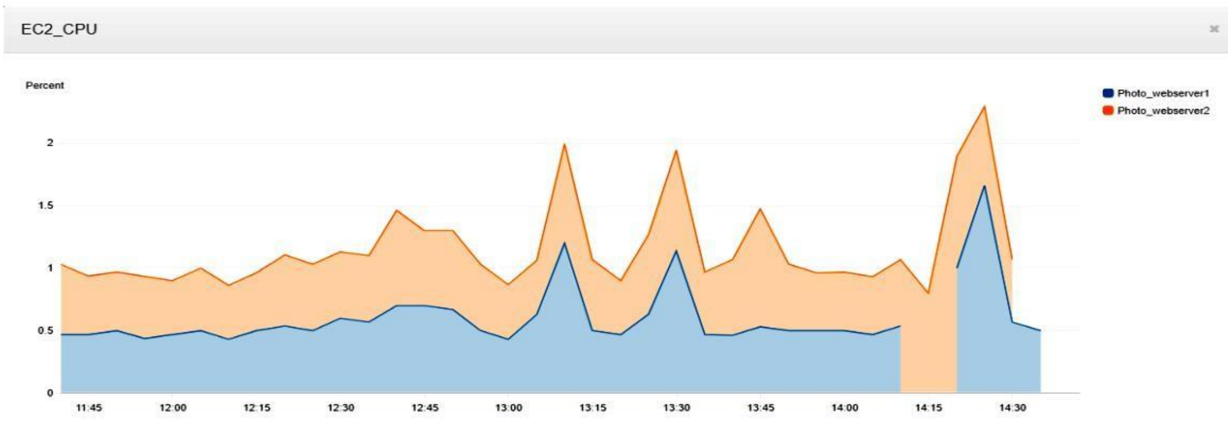

Fig. 7. Performance monitoring of system load

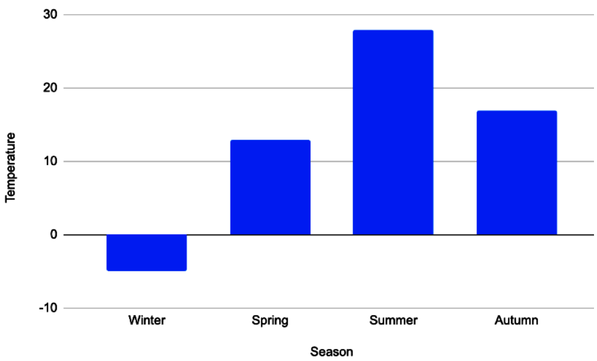

Fig. 8. Monitoring temperature sensors during different sports seasons

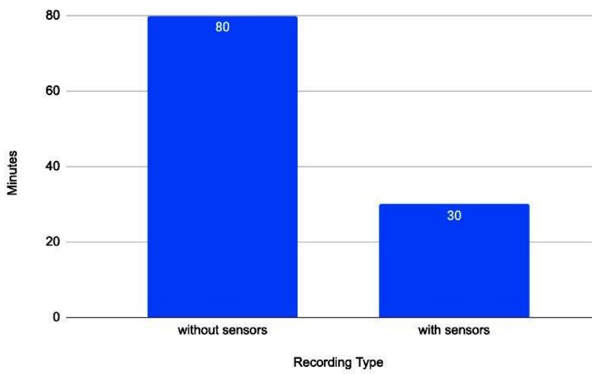

Fig. 9. Camera usage time without and with management sensors

When analyzing video with AI, challenges such as algorithm complexity, processing time, and accuracy arise. Complex algorithms, like object detection, can delay processing. Real-time processing of large volumes of data requires low latency and high accuracy. Improving system productivity and efficiency necessitates further optimization and refinement.

Evaluation of the performance of the cloud-based video recording system with embedded AI sensors demonstrates its advanced capabilities in data collection, analysis, and user interaction. The results indicate that the system effectively gathers video data while simultaneously monitoring environmental conditions, optimiz- ing energy usage, and facilitating user control.

Environmental sensors provide real-time insights into temperature, humidity, and air quality, enabling adjustments to training protocols to ensure athlete safety and performance optimization. Sensors ensure efficiency and reliability through dynamic energy consumption management and maximizing battery life, especially in portable or outdoor conditions.

User interaction sensors provide intuitive control and feedback mechanisms, allowing athletes, coaches, and instructors to initiate recording sessions, provide feedback, and interact with the system in real time. This fosters a collaborative learning atmosphere and enhances usability.

It is depicted (Figure 9) that the duration of ineffi- cient camera usage has decreased due to the integration of camera management sensors. So, sensor integration enhances performance and versatility in sports training and performance evaluation. It enables them to derive practical insights and intuitive control over their training processes.

9. Gratitude

The authors thank the Editorial Board of the Sci- entific journal “Measuring Equipment and Metrology” for their support.

10. Mutual claims of authors

The authors state that there are no financial or other potential conflicts regarding this work.

11. Conclusions

Key findings of current study include successful integration of hardware components with AWS, high performance, and real-time feedback. The cloud-based video recording system with AI opens opportunities for optimizing training and preventing injuries which repre- sent a significant advancement in sports technology, offering unprecedented opportunities.

References

[1] Chase, C. (2020). The Data Revolution: Cloud Com- puting, Artificial Intelligence, and Machine Learning in the Future of Sports. In: Schmidt, S.L. (eds) 21st Century Sports. Future of Business and Finance. Springer, Cham. https://doi.org/10.1007/978-3-030- 50801-2_10

[2] Chaudhary, S., Bhargave, V., Kulkarni, S., Puranik, P., & Shinde, A. (2018). Home Automation System Using WeMos D1 Mini. Int. Res. Journ. Engineering and Technology (IRJET) Vol, 5, 4238-4241. [Online]. Available: https://www.academia.edu/download/ 58283614/IRJET-V5I5944.pdf

[3] Crandall AS, Mamolo S, Morgan M. SkiMon: A Wireless Body Area Network for Monitoring Ski Flex and Motion during Skiing Sports. Sensors. 2022; 22(18):6882. https://doi.org/10.3390/s22186882

[4] Bershchanskyi, Y. and Klym, H., 2023, October. Information System for Administration of Medical Institution. In 2023 13th Int. Conf. on Depend. Sys- tems, Services and Techn. (DESSERT) (pp. 1-4). IEEE. https://doi.org/10.1109/DESSERT61349.2023. 10416537

[5] B.C. Kavitha, R. Vallikannu, IoT based intelligent industry monitoring system, in 2019 6th International Conference on Signal Processing and Integrated Net- works (SPIN), IEEE, 2019, p. 63–65. https://doi.org/10.1109/SPIN.2019.8711597

[6] Jaya, N.I. and Hossain, M.F., 2018, October. A proto- type air flow control system for home automation us- ing mqtt over websocket in aws iot core. In 2018 In- ternational Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC) (pp. 111-1116). IEEE. https://doi.org/10.1109/CyberC.2018.00032

[7] Dineva, Kristina, and Tatiana Atanasova. "Design of scalable IoT architecture based on AWS for smart livestock." Animals 11, no.9 (2021): 2697. https://doi.org/10.3390/ani11092697

[8] Dineva, K.; Atanasova, T. Security in IoT Systems. In Proceedings of the XIX International Multidiscipli- nary Scientific GeoConference SGEM, Vienna, Aus- tria, 9–12 December 2019; Volume 19, p. 576–577. https://doi.org/10.3390/ani11092697

[9] Jangid, N.K. and Gupta, M.K., 2022, June. Protecting software design in the cloud using AWS IoT. In Pro- ceedings of the 20th Annual International Conference on Mobile Systems, Applications and Services, p. 561-562. https://doi.org/10.1145/3498361.3538784

[10] Hakkı, S.O.Y., 2021. ESP8266 and ESP32 series of SoC microcontrollers. Programmable Smart Microcon- troller Cards, 110. [Online]. Available: https://www. isres.org/books/Programlanabilir Akıllı Mikrodenetley- ici Kartlar_01_16-12-2021.pdf#page=110

[11] Chakrabarti, A., Sadhu, P.K. & Pal, P. AWS IoT Core and Amazon DeepAR based predictive real-time monitoring framework for industrial induction heating systems. Microsyst. Technol 29, 441–456 (2023). https://doi.org/10.1007/s00542-022-05311-

[12] Sharma, V. (2022, April). Object detection and recogni- tion using Amazon Rekognition with Boto3. In 2022 6th Int. Conf. on Trends in Electronics and Informatics (pp. 727-732). IEEE. https://doi.org/10.1109/ ICOEI53556.2022.9776884