Cloud platform for biomechanical applications in sport and rehabilitation

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***Abstract*— Sport and rehabilitation are two very important research areas where biomechanical systems and applications are used. The use of sensors and smart equipment enables the measurement of motion parameters that were previously unknown or not available. Sensors can produce large amounts of data that need to be stored for later processing and analysis. It is also important that the cloud platform architecture is structured yet flexible enough to allow different types of experiments and applications to use a single cloud platform to some extent. This paper presents a universal solution that addresses these issues. We present the architecture for the proposed cloud platform that can accommodate all types of sensors, support different applications and measurements, track users through different tests, and produce standardized output types and reports.**

Keywords: Cloud platform, Biomechanical application, Application programming interface, Sensor, Sport, Rehabilitation

I. Introduction

We are witnessing a rapid penetration of various sensors into a number of research areas. In sports and physical rehabilitation, for example, the use of wearable sensor devices and smart equipment with integrated sensors has experienced growth in recent years. Biomechanical applications based on such systems are usually tailored to specific tasks and do not provide data portability or result matching between applications of different device manufacturers and research groups [1], [2]. It is difficult to use one type of software for several different applications or experiments. Commercial devices that can provide biomechanical measurements usually work with an application designed specifically for that device or task. We propose a solution that solves the problem of multiple independent systems by combining them into one platform solution. We propose a platform that is hardware-independent and allows data exchange between different devices and supports various levels of signal processing and data analysis.

Our main motivation was to design the system and implement the basic building blocks of a cloud-based platform for biomechanical systems and applications, which would solve our problem of having multiple biomechanical applications [3] that are self-sufficient and each of them has a unique storage structure for signal data, metadata and requires a unique analysis process. Another important aspect of this idea is the use of similar sensors and sensor devices in different sports disciplines and rehabilitation environments. This cloud platform will provide a standardized interface for sensor data acquisition and a universal storage solution that can be used for any sensor-based biomechanical application. Since devices are similar in different biomechanical applications and experiments, it makes sense to create a uniform backend environment for data manipulation.

One of our major goals was to develop a cloud-based platform for biomechanical systems and applications that is easy to use by trainers, teachers and therapists. The platform provides a web or mobile interface for various applications, such as tests and measurements of physical abilities, motion analysis and biofeedback applications. Similar, but less general architectures and cloud platforms have already been considered in [4]–[10].

The main research objective is to create a flexible system that is suitable for various biomechanical applications. Despite these similarities, applications can use different sensors and thus create different conditions. We focus on (wireless) sensor devices that measure kinematic and activity parameters and send the relevant data to the cloud platform. To enable the acquisition and retrieval of different signal and data types in a single data structure, a special database structure works together with a universal Application Programming Interface (API) and control interface to ensure adequate and reliable data processing according to the needs and requirements of the different biomechanical applications. Universality is only possible if the structure is divided into manageable but interconnected parts.

This paper presents the design process of the cloud platform for biomechanical applications. The requirements of the biomechanical system and the online platform are described in chapter II. The architecture of the cloud platform is described in chapter III. In chapter IV we present a typical use case and future work, we conclude with chapter V.

II. System requirements and design guidelines

In order to create a reliable platform, some pre-set standards and requirements should be followed. The requirements for the platform are mainly focused on the data and metadata received from the sensors as well as on the needs of the users and biomechanical applications. There are requirements that should be followed for each biomechanical system [11], [12]. Even more important are the general requirements for building online IoT or sensor platforms [5], [13], [14]. These guidelines should be considered when designing the platform.

A. Biomechaical signals and sensors

In biomechanical systems we use different sensors to measure the kinematics of the body or body parts. There are different types of sensors: wearable kinematic sensors, strain gauges, force plates, optical capture systems, electromyography sensors (EMG), and others. A typical wearable kinematic sensor used in biomechanical applications includes an accelerometer, a gyroscope and sometimes a magnetometer. Each sensor measures a physical quantity; it has its own units, dynamic range, and sampling frequency.

B. *Online platfom requirements*

1) Processing

Online platforms receive requests from different users or devices. The software must be able to prioritize different requests according to the processing needs. With respect to time, real-time or near-real-time device inputs are more important than metadata inputs. Online platforms must be scalable and portable so that they are able to change systems/hardware on which they run in a short time. The ability to run in multiple instances also increases performance.

2) Multiple devices and users

The platform should serve different clients (users and devices) independently. The platform is optimized to serve different requests from clients with responses or actions and should not depend on the number of clients or the type of communication. Devices are able to send data in a certain format with the correct authorization and the correct identifiers. Different restrictions apply to clients operating in separate modes (specific data from devices or users with specific privileges). Clients must be served according to their specifications and API definitions.

3) Data storage

Data is an important part of any online platform. Applications running on the platform have data storage requirements that the platform must take into account. The speed of the data (read and write) is the critical factor that determines the speed of the platform. Database system should be selected according to the speed requirements of the platform and the complexity of the data.

4) Data access, APIs

Data platform must allow other applications to interact with their data using API (Application Programming Interface). This allows data manipulation via a remote device and the use of multiple management applications in a single platform. APIs are required for both input and output. When data is received, it must be verified that it does not interfere with the existing data structure. APIs that output data must serve multiple applications or be application-specific.

5) User interaction

The user should be able to manipulate the system with a simple and easy to use user interface. The user interface of the platform should be designed according to the applications and user needs. Only users with the appropriate authorizations have the right to display or manipulate certain data.

6) Security

The platform must be secure against attacks on any open communication channel. Unwanted and malicious requests must be detected before response. If the application involves personal data, the standards and laws concerning personal data must be observed. Users can view their data and may allow the sharing of this data with other specified users; such as trainers and therapists. Before the general use of data that may contain personal information, the data must be anonymized. Users must be able to request the permanent deletion of private data or its anonymization.

C. *Custom implementation requirements*

Our proposed system must implement the above requirements, but the implementation of the system will be done in stages. In the first implementation phase, the system will not support real-time operation.

The proposed system must be able to handle and distinguish between two major types of sensor data: streaming and asynchronous. Streaming data corresponds mainly to sensor signals. Asynchronous data are various triggers, events, results and other important metadata.

In the second stage, it is expected that the platform will allow the execution of application specific scripts and software on the platform. Certain data analysis tools for rapid signal analysis and statistics will play an important role in the future use of the platform.

III. Platform Architecture

The platform is designed to handle multiple device and user types. The general design scheme in Figure 1 shows the high-level architecture of the proposed platform. It consists of four parts: 1) Ingest API that can receive multiple transport protocols and data structures, 2) Web application with control API that allows the operator to manage the entire platform, 3) database with a relational structure, and 4) data export with post-processing and user APIs.

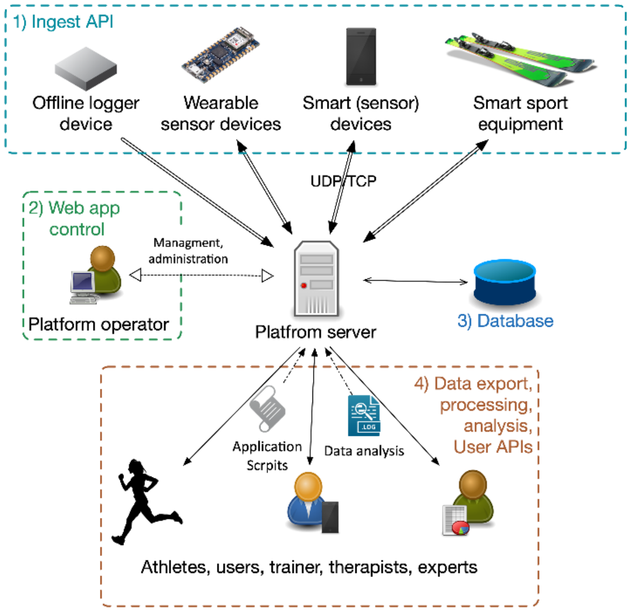

Figure 1: General architecture of the proposed platform. Most basic components can be divided into groups: 1) input devices connected to the ingest API, 2) web application for management and control, 3) relational database, and 4) post-processing and output devices.

The server is connected to the database, implementing the platform functionality and specific application scripts. The signal processing and data analysis is considered a separate function and includes user-defined analyses, signal display interfaces, and special back-end operations that can be application-specific. The difference between application scripts and analysis tools is that application scripts are designed for future near real-time operations.

Different types of users interact with different functions of the platform. We define: athletes and patients as *users* (providing data); coaches, instructors, trainers, therapists as *platform operators* and *professional users* (data management); researchers, scientists, data analysts; administrators, engineering professionals as *platform operators*. The platform operator is the user designated to collect and manage application data. The platform operator can manage one or more applications running on the platform. Administrators and engineers can manage multiple applications and the platform itself, while other professionals can access only designated applications. The operator only manages the data necessary to work with clients. Users are providing data and they can interact with platform depending on the application being used. Users can provide data with wearable sensors via platform operator or they can interact with the platform via personal devices and custom applications. Finally, experts perform data analysis by examining the stored data.

The platform enables the export of stored data for further offline studies in the form of reports and raw data.

Nevertheless, it is expected that the platform will help with some feedback functions by returning computed data or feedback information to the athlete, coach, or therapist in near real-time [15].

A. Platform components

The platform is designed as a universal sink for real-time and non-real-time signal and data acquisition for all kinds of biomechanical applications. The platform shall support high data rates and signal sampling frequencies. Since the structure is universal, other applications can also be managed.

1) Ingest API

The front-end of the platform, which interacts with sensor devices, is an ingest API. This API allows sensors to send data according to a defined structure with different transport protocols. There are different requirements for metadata than for streams from high sampling rate devices, both of which must be considered when implementing the API. Streams coming from sensor devices are processor-intensive, as the sampled signals usually enter the API sample by sample. Asynchronous events also come from other devices that provide metadata about signals. The Ingest API should provide a means of synchronization of multiple devices used by the same application.

Sensor devices send data to the platform in a format that is as compressed as possible to enable high data flow with minimal redundancy. For this reason, the platform expects the data in the raw transport protocol format. The signal variables are predefined in sequence and structure. Sensors that use existing structures and standards for communication are implemented with the extension of the API to allow different formats and structures depending on the specific application.

Offline measurements recorded with previous prototypes can also be imported into this platform, allowing the use of built-in tools for analysis and unification of data from the same experiment recorded both offline and online. Each excision application has a specific data structure that requires an application-specific import API. If the existing database structure would need to be restructured to make the data compatible and integrated into the platform structure, a custom utility and manual metadata definition by the platform operator would be required.

2) Web application and control API

To control the platform, a web application with the corresponding API is required. This allows the assignment of metadata, experiment and measurement parameters. Depending on the biomechanical application, the operator of the platform or the user interacting with the API has the possibility to add or change athlete/user parameters, define devices and sensors, assign them to experiments, start and stop measurements. The operators can also import or export data accordingly. The control web application is an integral part of this platform and is designed to operate many applications, but it is not exclusive. Control API can be used by other applications. This allows the development of mobile, desktop or professional (biofeedback) applications, while the platform continues to be used for storage and other functions included in the proposed platform.

3) Database structure

We have designed the database to be as universal as possible. We have studied the general needs of biomechanical applications and combined the understanding of sport and rehabilitation with the specific technical requirements. We designed a relational database; Figure 2 shows only logical connections between the entities and leaves out some technical details of the database.

We designed a database structure that consists of three logical parts. The basic components, users, experiments, devices and sensors, defining the necessary input elements are shown on the left side of Figure 2. The definition of an experiment is a specific activity with specific devices including specific sensors.

The second part consists of connections between sensors, devices, experiments and users. This is shown in Figure 2 with blue arrows. Sensors are an integral part of the device; one or more devices can be used in an experiment. The main combining entity is the measurement, which is defined as an activity of a person according to the experiment parameters at a certain time and place. There can also be more than one repetition of each measurement, and the repetition defines an iteration of the same kinematic action stored in the database. Finally, the database actually stores data from sensors and devices and links this data to metadata.

4) Data export, processing, analysis and user API

Stored data can be used in three basic ways: exported data, predefined platform-enabled data analysis, and other applications. Data export enables the operator to share stored data to other signal processing or data analysis tools; including exports for data analysis experts. These exports should be in a format required by the targeted analysis tools. The predefined platform-enabled data analysis enables users to interact with signals, data in a web report format including charts, tables, reports, and other forms of data presentation. We have designed the platform so that application-specific scripts can be executed on this platform and application-specific data can be returned to athletes, coaches or therapists. This enables feedback or at least augmented learning. This is achieved by means of a user API that contains both integrated calls and application-specific scripts.

Only those individuals that have the right to view certain data have an ability to export these data or access the API. In the case of relationships, athlete-trainer and patient-therapist, both users can see data of measurements where they both participated. In some cases, athletes and patients do not have access to the platform and their data. For example, when the user has a designation of an expert, only anonymised data is shown or exported, as personal data are not needed for scientific studies. Personal information will be shared only when athletes or patients wish to share their data with some other user; athletes may share information with multiple trainers, patients may request for a second opinion.

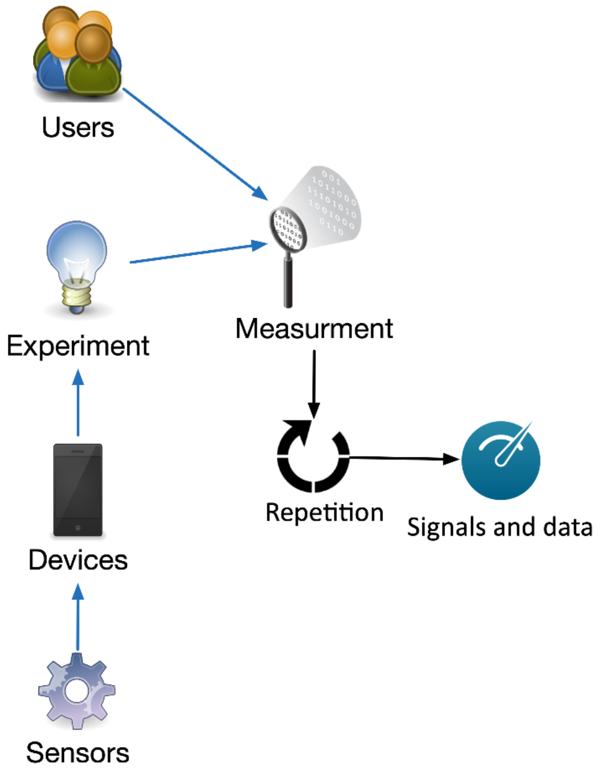

Figure 2: Simplified database model. Basic input entities are users, experiment, devices, and sensors. Blue arrows, measurement and repetition represent relationships between basic entities. On the right, the model show signal and data storage in regards to metadata.

B. *Functionalities and operation*

The operation of the proposed platform is quite simple for a user or operator. This is due to the fact that most of the operations related to data are automated. What the platform operators have to manage is metadata that cannot be obtained from sensors. This platform can be run as software on a personal computer, provided that the hardware is capable of operating the platform, or it can be part of a cloud infrastructure. This depends on the necessity of a biomechanical application. Some applications require real-time operation, which is only generally possible only when the server is on the same network as the devices. Even when the application runs locally, the data can be synchronized with the cloud part of the platform.

The operator manages the (meta)data in the platform using a web application or controls the API in another application; the elements and parameters that the operator can change depend on the rights and needs of the application. In general, the operator assigns sensors to the devices and the devices to the experiment. The operator also defines their properties and settings. If those settings have been previously assigned, only the user and the measurement information are required.

The operator adds a new user with common morphological parameters. If the person was previously assessed, only the changed morphological parameters can be added. The platform can receive data from sensors when the measurement is created. A measurement is formed by combining the experiment information, user data, time, date, and place. The ingest API can now work independently from the operator to store sensor signals and data. Depending on the application, the API or the operator control the start or stop of the sensor signal and data recording.

When the measurement is complete, the operator can use the stored data to perform a signal analysis and display the acquired signals in a graph. At this point, the operator can choose to export the data for more detailed analysis or just save the data for later use. The operator can also leave these tasks to other users with different privileges.

Multiple operators or users can work on this platform simultaneously. Only the number of physical devices available limits the number of users using a biomechanical application. This is because each device has a unique identifier that is used by the Ingest API when data is stored in the database.

IV. USE CASE AND FUTURE WORK

There are a number of existing and possible future biomechanical applications and systems suitable for the proposed platform. One of the applications that we are currently using and that would benefit from this platform, is a measurement system for precise pistol shooting [16].

Our shooting application currently uses its own database structure that stores sensor signals and application metadata. The structure is different from the one proposed in this paper, but it is possible to integrate the application data and functions into the proposed platform. The shooting application can also be used in the future in an almost unchanged form, the only difference would be to use the control, ingest and user API of the platform instead of the internal database. There are certain operations performed by this custom software in relation to shot visualization that would be difficult to implement as an add-on to the web control interface in the proposed platform, but they can be performed in parallel with the platform.

This is a single isolated example of an application that could benefit from the proposed platform. For the future, we see this as a multi-tiered platform that includes different functions, built for different systems, but using common communications and protocols to provide ease of use for users and operators.

V. Conclusion

Biomechanical applications are a relatively new field of research. The proposed platform is designed to be universal to support a wide range of applications. The service offered by the proposed cloud platform may change the way biomechanical applications are designed, developed and used. We are dealing with a considerable amount of data, so this solution can be seen as a kind of a big data problem for the near future.

Some challenges we want to pursue in the future are the use of different data storage architectures and non-relational database models. This could significantly increase speeds and reduce database complexity. This approach could also be beneficial for future biomechanical applications. Nevertheless, conventional technologies will be used at this stage of development to demonstrate the practical suitability of the system. The presented cloud platform will grow organically, according to the needs of the biomechanical applications.

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