Real-time Analysis of Physical Performance Parameters in Elite Soccer

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***Abstract*—Technology is having vast impact on the sports industry, and in particular soccer. All over the world, soccer teams are adapting digital information systems to quantify performance metrics. The goal is to assess strengths and weaknesses of individual players, training regimes, and play strategies; to improve performance and win games. However, most existing methods rely on post-game analytic. This limits coaches to review games in retrospect without any means to do changes during sessions. In collaboration with an elite soccer club, we have developed Metrix which is a computerized toolkit for coaches to perform real-time monitoring and analysis of the players' performance. Using sensor technology to track movement, performance parameters are instantly available to coaches through a mobile phone client. Metrix provides coaches with a toolkit to individualize training load to different playing positions on the field, or to the player himself. Our results show that Metrix is able to quantify player performance and propagate it to coaches in real-time during a match or practice, i.e., latency is below 100 ms on the field. In our initial user evaluation, the coaches express that this is a valuable asset in day-to-day work.**

***Keywords*-Athlete tracking; activity assessment; sport analysis; motion tracking; automated training assistance**

I. Introduction

Research in the last decade shows an increased demand on the physical performance of elite soccer players [1], indicating that the bar is continuously being raised as the sport evolves. Through technological advances in the use of quantified data and associated analytics, teams obtain valuable insight into performance metrics, serving as a foundation for evidence-based decisions regarding team improvements. The volume and immediate availability of such data allows coaches and sports scientists to make more informed decisions about current and future needs, i.e., optimizing the individual players fitness and/or freshness and thereby increasing the teams' potential to perform.

Due to the non-linear flow of a soccer match, automated analysis is inherently difficult. There are already a lot of parameters to consider during the game, and additionally, there are parameters like pre-game nutrition and post-game recovery that influence the performance. One commonly used approach is player-centric analysis, where teams collect large volumes of performance metrics regarding each individual player. Teams create extensive profiles on their players, holding information the coaches deem relevant for maintaining and increasing player performance. As data volume and complexity grow, efficient tools for automated high-precision retrieval become essential. However, data quantification methods mostly rely on post-game analytics, using automated or semi-automated tools to study performance metrics. This is often achieved through video based analysis tools or data captured by sensor devices [2]. Posterior evaluation is useful for hindsight notation, allowing coaches to apply corrections thereafter. Its weakness, however, is the lack of immediate feedback *during* matches and practice sessions, in situations that might require swift action from the coaches.

In this respect, we present the *Metrix* system providing live monitoring and analysis of player performance on the soccer field such that coaches can react to events in real-time. Parameters considered imperative by coaches are captured by our system and immediately made accessible through mobile devices or laptops operated on the field during match or training sessions. Experiments show that Metrix efficiently performs real-time analysis of players' position data captured using wearable sensors. Metrix is able to detect, process and propagate captured field-events with an end-to-end latency measured to be less than $100\,\mathrm{ms}$ with 25 players on the field, i.e., the system is able to provide real-time feedback to the coaches. Moreover, an initial user evaluation shows Metrix is useful for monitoring physical performance parameters and may have a positive impact on the individualization of physical training load, and coaches express they would like to use Metrix on a daily basis. In this paper, we describe the system, and we demonstrate the tool at the conference.

II. Methods

Metrix is a software system that provides soccer coaches with tools to quantify specific movement patterns of players, in relation to individual training goals and physical demands of different playing positions on the field. It is developed for and in close collaboration with coaches of an elite soccer club in Norway. The functionalities our system provides are implemented based on the coaches' specified requirements, and further customized to their needs.

Metrix is a web application, accessed by users through standard web browsers. We chose this interface technology and not an app so that the coaches can use any type of portable device, be it a phone, pad, tablet, PC, or even a big screen next to the soccer field.

Sensor data from the soccer field are captured and processed by the Metrix backend in real-time. The backend is responsible for parsing and analyzing sensor data, correlating it with physical performance parameters defined by coaches. Computed performance metrics are further distributed to connected clients through the frontend message manager. Users receive updates from field events through the Live Session interface in the client, implemented as a Single Page Application (SPA), which relies heavily on client-side scripting for serving the data in real-time.

A. Data Sources

Our primary source of data is player movement during sport events (matches and trainings) using the ZXY Arena Sports Tracking system (ZXY) [3] from ChyronHego. ZXY is a highly accurate Local Position Measurement (LPM) system, based on the $2.45\,\mathrm{GHz}$ Industrial, Scientific and Medical (ISM) band radio signals from sensor belts worn by athletes to stationary receivers mounted around the stadium. The receivers are mounted in overlapping zones around the pitch to eliminate signal blocking and occlusion zones on the field. Each receiver independently computes the belt's position and trajectory on the field based on received signals. Our current setup uses a per belt sampling rate of $20\,\mathrm{Hz}$, transmitting data records in real-time to a central relational database, which merges and stores all signals. The ZXY belts are also issued with accelerometers, a gyro, and a compass. Although Metrix can make use of traditional GPS based positional input sources, LPM systems generally provide better accuracy [4].

Prior to a match or training, coaches distribute sensor belts among the players and activate them through a designated ZXY subsystem. When a coach starts a new session, Metrix will connect to the ZXY Sensor stream, receiving raw sensor data records through a TCP connection. The output data records contain measurements from exactly one ZXY sensor belt. Belts are uniquely identified by a tag id, and each player wears exactly one belt.

Each ZXY data record is comprised of an array of sixteen unique data fields, measured by the sensor technology. The fields include positioning, direction, speed, etc. In our system, we need only concern ourselves with a subset of the data including the ID of the ZXY sensor belt, the local UNIX timestamp, the current speed of the player, the current acceleration of the player, and the cumulative distance the player has moved so far. Metrix will parse the data records and further deserialize the content into internal data structures.

Note that the data is collected from player activities routinely measured during the competitive season. Therefore, a usual appropriate ethics committee clearance is not required [5]. Nevertheless, team and player confidentiality is ensured by anonymisation of all data, written informed consent from players and an approval from The Norwegian Centre for Research Data.

B. Event Model

There are many types of interesting events and metrics that can be extracted from our sensor data. For this paper, we focus on two classes of movement data: run events and acceleration events. We count the number of occurrences of each event class and its duration in terms of distance covered.

1) Run events: A run event indicates movement of a player within certain speed zones. Metrix is configured to use two specific zones, both well established standards in the literature [6], [7]. A *high intensity run (HIR)* is a run at a speed faster than $5.5\,\mathrm{m\,s^{-1}}$ over a time period greater than $1\,\mathrm{s}$. A run at a speed faster than $7.0\,\mathrm{m\,s^{-1}}$ over a time period greater than $1\,\mathrm{s}$ is said to be a *sprint*. Figure 1 shows an example recording of a typical run-event containing both HIRs and sprints as captured by Metrix. The run is characterized by the six markers A to F as follows:

- **A** Start run: speed increases above $4.0\,\mathrm{m\,s^{-1}}$.
- **B** Start HIR: speed increases above $5.5\,\mathrm{m\,s^{-1}}$.
- **C** Start sprint: speed increases $7.0\,\mathrm{m\,s^{-1}}$.
- **D** End sprint: speed decreases below $7.0\,\mathrm{m\,s^{-1}}$.
- **E** End HIR: speed decreases below $5.5\,\mathrm{m\,s^{-1}}$.
- **F** End run: speed decreases below $4.0\,\mathrm{m\,s^{-1}}$.

During event processing, Metrix captures the timestamps (t) and cumulative distance covered (d) from event markers A through F. The time from B to E asserts a valid HIR only if $t_E - t_B > 1$. If the run is valid, the time interval $t_F - t_A$ defines the duration of the run, and the distance $d_F - d_A$ defines the distance covered during the event. If the speed increases above $7\,\mathrm{m\,s^{-1}}$, a valid HIR run becomes a sprint.

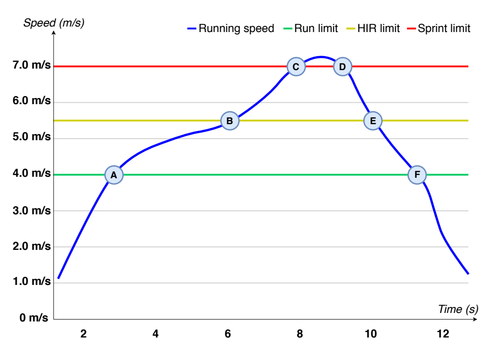


Fig. 1. Example of a run with different speed zones.

2) Acceleration events: The definition of an acceleration event is similar to the run event, but is derived from different sensor parameters. An *acceleration* is changes in speed of more than $2.0\,\mathrm{m\,s^{-2}}$ over a duration of $500\,\mathrm{ms}$. Figure 2 shows an example recording of the accelerations of a player as captured by Metrix. The captured acceleration events are defined by the following four markers:

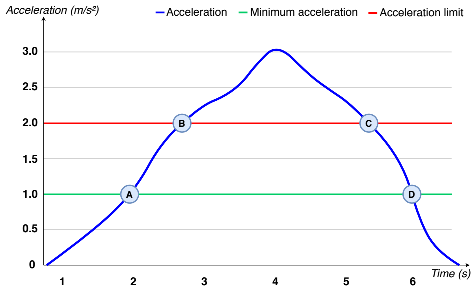


Fig. 2. Example of accelerations during a run.

- **A** Start acceleration: acceleration increases above $1.0\,\mathrm{m\,s^{-2}}$.
- **B** Start valid acceleration: acceleration increases above $2.0\,\mathrm{m\,s^{-2}}$.
- **C** End valid acceleration: acceleration decreases below $2.0\,\mathrm{m\,s^{-2}}$.
- **D** End acceleration: acceleration decreases below $1.0\,\mathrm{m\,s^{-2}}$.

Similar to runs, the property $t_C - t_B > 0.5$ most hold for the event to be considered valid.

C. Data Processing Subsystem

Metrix includes a distributed data processing subsystem for analyzing sensor data and detecting on-field events. The data processing subsystem is designed with player analytics in mind. We apply the well-known controller-worker software pattern for this. Each active player in a session is therefore allocated its own worker process, responsible for processing all data records attributable to that particular player. Each worker is also allocated its own named job channel. The controlling orchestrator handles the detection and initialization of active players on the field. For performance reasons, player data is fetched and stored in memory for the duration of the on-going session, indexed through a map. Once a player has been identified, the orchestrator initiates a new worker assigned to that specific player.

Using per-player workers, Metrix improves concurrency, facilitating our requirement of serving player feedback in real-time. Assuming the server uses multiple cores, we achieve parallelism on a critical path in the data pipeline, ensuring low processing duration of field events. Assigning distinct worker routines to specific players in each session also provides a logical separation between processing tasks, reducing the need for synchronization and communication between worker threads as each worker only concerns itself with a unique subset of the data.

D. User Interaction

Authenticated users are presented with several interfaces allowing them to interact with Metrix. Training sessions are scheduled intermediate of official matches. For professional soccer teams, this often involves recovery, followed by sessions focusing on technical tactical aspects and physical work-out, often in a combination. Trainings are carefully planned and executed with regards to physical load and intensity. It is the coaches responsibility (and challenge) to find the balance between obtaining the desired training goals, and keeping the freshness of the players before an official match. Thus, there is a need to plan and monitor all activities. For example, a coach may require the central mid-fielders to achieve 70% of match-load over a period of four days. By quantifying specific load-intensive performance metrics, coaches can better monitor their players on a granular level. Players who are pushing themselves too close to the limit can be rested from specific drills, while those who are underloaded can receive additional physical load.

1) Week Planner: Metrix implements a Week Planner interface where coaches can set player-specific training goals within the current training period. The functionality of the Week Planner is primarily influenced and specified by the coaches involved in this project. As shown in Figure 3, our client displays a table of all the players in the team, as well as 0–100 percent adjustable sliders for each physical performance parameter we measure with Metrix. The percentage is calculated based on each player's all-time best performance. For example, if a player's highest value of sprint in an official match is 300 m, and coaches expects him to perform 50% of that during the week, his goal will be to achieve at least 150 m sprint. The initial best-performance values are gathered from historical match data, provided by the ZXY system. Submitted goals associated with the current training period are stored in the Metrix database, its values further used to portray the players goal on the progress bar during a live session, as we describe next.

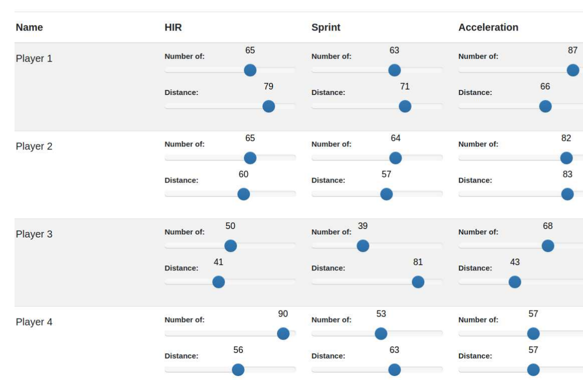


Fig. 3. Planning individual weekly training load (player names anonymized).

2) Live Session Cards: To avoid exceeding planned workload of individual players, we use live session feedback. The Metrix Live Session interface organizes player data in visual structures called *cards*, as show in Figure 4. There is one card for each player. A player's card displays live data when he is participating in an on-going match or training session. The cards are updated in real-time in response to received data.

Each card is divided into a header and a body section. The card header contains the player's name (1), sensor belt id (2), and a button (3) for listing detailed performance data from previous training sessions in the current week. Extra details are displayed in a popover, only visible through user interaction. The card body consists of six progress bars, visualizing number of conducted HIR (4), sprint and acceleration events, as well as distance covered during them. Progress bars display accumulated performance metrics from the entirety of the training week. A small marker on the bar (5) indicates the preset goal that coaches have set for the player for the current training period. The end of the progress bar (6) is defined by the player's all-time best performance. Taking into account that the player may exceed this limit we also show the values explicitly with a label (7) in the center of the bar. The label show *accomplished value* out of *weekly goal* (e.g., 129 / 243 HIRs in the figure).

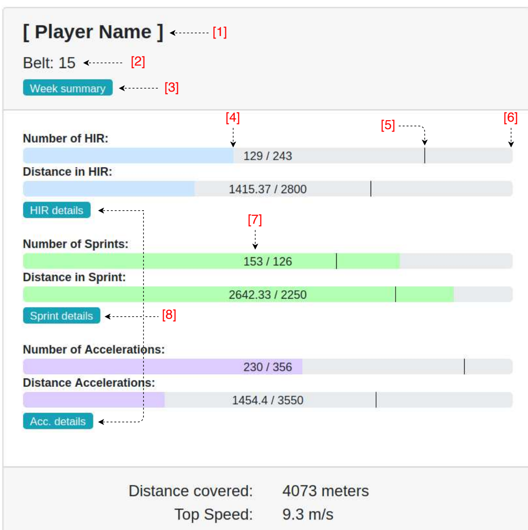


Fig. 4. Detailed view of a player card.

Users may request a detailed view of completed events by the click of a button (8). Detailed data is comprised of single events, arranged in a table, containing additional information on each of them. Event details are displayed in a popover, shown and hidden by user interactions. Figure 5 shows an example of a detailed view on completed sprints for a specific player. Each event in the detailed view is coupled with a button for playing a video of the performed event. When pressed, a video player will pop up and display the requested content.

Thus, based on these interfaces, the coaches can bring small devices onto the field and immediately see and take actions if particular players reach the planned load or if someone is underperforming.

3) Video Service: The Metrix video service allows coaches to request video playback of player events during an ongoing session ("Video"-button in Figure 5). As of today, the video component is conceptual, demonstrating that it is possible for real-time video playback of transpired events during trainings or matches. The service is based on the *Bagadus* [8] architecture, that records and stores video data on a daily basis. The video is stored in DASH-like segments, and video clips are described in manifest files generated on the fly

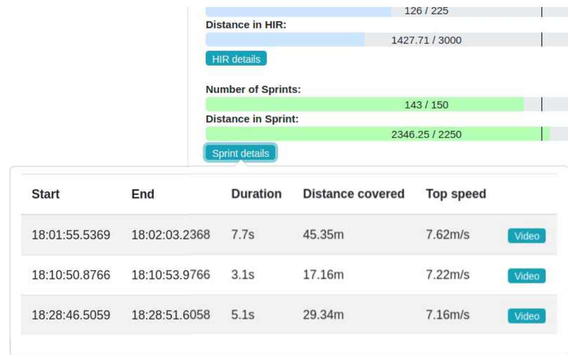


Fig. 5. Detailed view of session events (from Figure 4).

based on the given timestamps of events, similar to the query methods described in [9]. Thus, the sensor data timestamps are matched to the corresponding video segments. These are included in the manifest, and video event playout is managed by the video player.

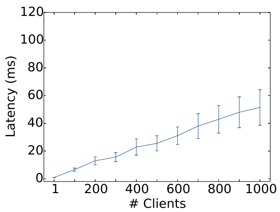
III. Evaluation and Results

To evaluate Metrix, we have performed several experiments. The following will describe our performance experiments on end-to-end latency, and our user satisfaction survey.

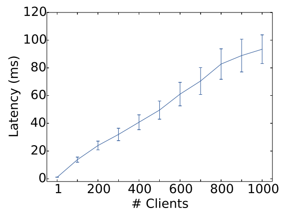
A. *Analysis latency*

The performance evaluation of Metrix concerns the systems capability of processing physical performance parameters and delivering the results in real-time. The sensor data input volume increases linearly with the number of players on the field, and our experiments therefore cover two realistic scenarios: an official match with 10 outfield players and a training session with 25 players in the squad. Additionally, we are interested in how our system scales with regards to an increasing number of coaches and other staff using Metrix simultaneously. In order not to affect the real running system, we have simulated sessions using real ZXY sensor data from a captured dataset [10]. As in the running system, the simulated ZXY server transmits data records at $20\,\mathrm{Hz}$ for $45\,\mathrm{min}$ (one period). For the 10 player experiment, there is a total of 221 events captured by Metrix, distributed among the players. In the 25 player experiment, we have duplicated some of the player data, resulting in a total of 525 captured events. Metrix is deployed on a desktop computer with an Intel Core i7-2600 processor, and the ZXY data server runs on an Intel Core i5-4200M workstation. All units use the same $1\,\mathrm{Gbps}$ network, consequently resulting in close to zero network latency.

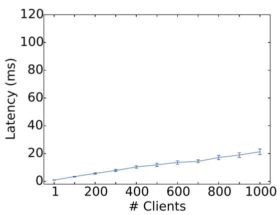
Figure 6 shows the results of the end-to-end latency on captured events from the match. We observe that the average latency approximately doubles when increasing from 11 (Figure 6(a)) to 25 (Figure 6(b)) players. and the graphs show that the latency scales linearly with the increasing number of clients. Average latency during the $45\,\mathrm{min}$ session is below $100\,\mathrm{ms}$, with both 11 and 25 players on the field, and up to 1000 clients using Metrix. In a typical use-case, with no more than two or three coaches using Metrix simultaneously, we have latencies (in the no delay network) of less than $10\,\mathrm{ms}$.



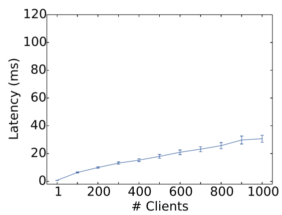
(a) 11 players, 221 events.



(b) 25 players, 525 events.



(c) 11 players, 221 events.



(d) 11 players, 535 events.

Fig. 6. End-to-end latency with 11 and 25 players. The error bars show the 95-percentile confidence interval. In Figures (c) and (d), we have no 5-second periodic client update.

If the users do not need periodic updates, but rather want to query for the current status, we can observe in figures 6(c) and 6(d) that both the latency and the variance are greatly reduced, indicating that there is some significant overhead in the message manager (even though the experiment pushes updates to an unrealistic high number of users).

As our end-to-end latency is measured between devices operating on the same network, wide-area latency is not properly assessed through our experiments. In a real deployment, we expect the general latency to increase, depending on factors like client bandwidth or the proximity to the server. Nevertheless, the increased network latency is in the area of 10 to $100\,\mathrm{ms}$. This is considered sufficient as users are not expected to be able to react to feedback any quicker.

B. User Evaluation

Metrix has been developed in collaboration with real end-users. A user survey is therefore an appropriate method to evaluate its value. However, since Metrix is only in pre-production use, we base our evaluation on a user-oriented presentation, involving an extensive demonstration of Metrix and its implemented features. The demo was followed by a questionnaire, evaluating Metrix by three main categories of statements; functionality, design and overall interest in using Metrix (the questionare is available in [11]). Four coaches with experience from elite and the Norwegian national soccer teams participated, and rated the statements using a balanced 5-point Likert scale (i.e., using the response scale: strongly disagree, disagree, neutral, agree, or strongly agree).

The answers from the functionality questions Q1–Q6 in Figure 7 indicate that the assessors consider Metrix will improve objective monitoring of player load, and can be very useful to accomplish weekly training goals. The survey also indicates that the assessors were diverged on our question about Metrix enhancing the individualization of training programs during trainings (Q4). Some assessors strongly agreed, while others were neutral. We speculate that this variance might be rooted in how coaches prepare the training sessions in advance. For the design questions Q7–Q9 in Figure 7), the assessors agree that Metrix provides a user-friendly interface, where data is presented in an intuitive way. The assessors also said that the progress bars made player performance data easy to comprehend. Finally, the question Q11 shows the willingness to use such a system. In short, the assessors clearly believe Metrix can be impactful (Q10) for individual training load monitoring, and that it enhances coaches real-time intervention potential. All the assessors state that they would use Metrix on a daily basis if provided.

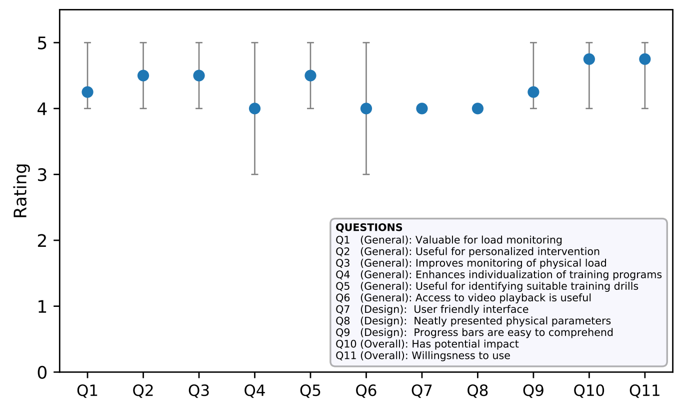


Fig. 7. User survey questions (Q) using a 5-point Likert scale.

IV. Discussion: Quantifying and Analyzing Soccer

Match analysis in soccer generally refers to the objective measurements and analysis of discrete events during training or competition [12]. Typical parameters include total distance covered, number of turns, and number of efforts performed in varying movement categories, i.e., jogging, running, sprinting [13], [14]. This information is used to develop extensive player activity profiles [15], outlining average physical demands of each player and their playing position on the field. Structured match analysis dates back to the 1970's [16], where coaches used *notational (pen and paper-based) analysis* to capture field events. An improvement to the classic notational analysis is *video-based time-motion* analysis, involving players to be filmed during match or training [17]. Video footage is analyzed post-game, allowing observers to pause, review and slow down the videos for a closer look. With the advancements of digital technology, more semi-automated systems have replaced the manual approach of collecting player data. The perhaps most renown system is ProZone [18], now called STATS, who in the early 2000's introduced a semi-automated video tracking solution using multiple cameras placed in fixed positions at the stadium, covering the entire field. In later years, commercially available GPS units designed for sports tracking have become increasingly popular for quantifying player performance metrics [19],

[20]. The most renown systems using this technology includes GPSports [21], CatapultSports [22] and StatSports [23]. With advancements in GPS technology, the sensor components have decreased dramatically in size, now considered non-invasive for players to wear underneath their clothing during physical activity. Furthermore, another way to analyze the game is using video. Bagadus [8], [24] is a real-time sports analysis system providing instant video playback, but there is not automatic analysis of data involved.

In short, several approaches exist with different methods for collecting data. To the best of our knowledge, there are however few, if any at all, that actually perform analysis and give feedback in real-time allowing the coaches to act immediately. As a possible solution to fill the gap, we present our Metrix system targeting real-time feedback based on the ZXY position sensor system [3] mentioned above.

V. Demonstration

The demonstration of the system shows how the application can be used in day-to-day coaching during sessions. We simulate a realistic ZXY data transmitter that provides sensor data from a recorded match recorded, i.e., the simulator provides Metrix with sensor data identical to how it is received on the field. Furhter, we show how Metrix detects physical events on the field in real-time, and projects them to the player statistics board in the web interface. While the match simulation is running, we will be able to see a more detailed view of each event on each of the players, and see how they progress towards (or exceeds) their training goals.

VI. Conclusion

This paper describes Metrix, a novel cyber-physical system system that enables real-time monitoring of elite soccer players during matches and training sessions. In particular, Metrix provides real-time analysis of each individual player's position data, which is key to providing coaches with the toolkit they need to quantify specific movement patterns and analyze training loads in relation to preset training goals. Metrix also provides a method for coupling sports events with video recordings, allowing coaches to view replays of player-performed events.

Our evaluation shows that Metrix efficiently performs real-time analysis of the ZXY sensor data, with an end-to-end latency to process and propagate captured field-events measured to be less than $100\,\mathrm{ms}$ with 25 players on the field. Our user study shows that coaches find Metrix a highly useful tool for monitoring physical performance parameters and might have great impact on the individualization of physical training load. The questioned users express they would use Metrix on a daily basis if it becomes available.

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