In Situ Sports Performance Analysis System Using Inertial Measurement Units, High-FPS Video Camera, and the Android Platform

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***Abstract*—We developed a mobile sports performance monitoring system that incorporates the use of inertial measurement units or IMUs, a high-fps video camera, and an Android tablet to provide quantitative and visual assistance to coaches and athletes in the actual location of respective sports. An Android app was developed to wirelessly communicate via Bluetooth and Wi-Fi to control the IMUs and video camera in recording high frame rate video and motion data. The app then graphically presents the motion data along with their corresponding frames from the video. With the system, coaches and athletes can easily analyze sports performances, decide the necessary courses of action to improve on them, and easily share the data in a group for peer discussions and consultations.**

***Keywords*—wireless inertial sensors; motion analysis; sports performance monitoring; data socialization**

I. Introduction

Numerous studies [1-4] have shown that inertial measurement sensors have potential use in sports performance analysis. These studies favor these sensors due to their lightweight and wearable nature [1][2] as well as them not having a very complex installation or setup [3]. Although other methods were also capable of use in sports performance analysis, they were more inclined in being research equipment rather than tools coaches and athletes would use on a regular basis [1][3]. Additionally, it was stressed that the use of the sensors for sports performance analysis must be in situ or in their original location for the integrity of the motions as the mentality of the athlete and conditions of the environment are quite different in a laboratory setting [1].

Regarding the data analysis itself, it has been mentioned that giving it out in real time isn't practical as coaches would still prefer watching the performance of their athletes with their own eyes before looking at the data. Thus, the performance analysis is only needed in near-real-time and in a presentable manner during the analysis to postmortem phase. Additionally, since inertial sensor data is purely quantitative, it was suggested that the data be integrated with video to support it [2].

In this paper, we will present a system that takes into account those mentioned in the aforementioned studies regarding the use of inertial sensors for sports performance analysis. The system will aim to provide actionable data to assist the coaches and athletes in monitoring and improving their performances. With digitally-recorded performance data and synchronized video in a portable tablet interface, details of the performances will be easier to recall and will complement the qualitative assessments of the coaches and athletes.

II. System Overview

The system, appropriately called Assistive Sensor System for Sports and Rehabilitation or ASSESSOR for short, is comprised of 3 parts – inertial measurement units for motion and orientation data acquisition, a high-fps video camera for visual data acquisition, and an Android tablet with the ASSESSOR app for data recording, analysis, and storage – all of which are shown in Fig. 1.

Fig. 1. Assistive Sensor System for Sports and Rehabilitation

The ASSESSOR app is responsible for controlling the IMUs and video camera wirelessly to start and stop recording. Once a performance is done recording, the app can then load the motion data and video data into a synchronized manner with each motion data sample being shown with its corresponding frame from the video based on their timestamps. The graphs of the motion data can then be easily attributed to their respective motions.

A. Hardware Components

1) Inertial Measurement Units

The MEMS IMUs used in the system are comprised of a 3-axis accelerometer, 3-axis gyroscope, and a 3-axis magnetometer. These wireless sensors, communicating through Bluetooth, are from Life Performance Research, Inc. [5] and are bundled with a PC program and an Android library for accessing the raw motion data (acceleration, angular rate, magnetic field) and orientation data (quaternion, Euler angle).

With dimensions of 45 x 37 x 20 mm and a weight of 37 g, they can be considered as unobtrusive when attached to the body of the athlete and would not drastically affect their performance. Additionally, with an internal 800mAh Lithium battery powering the IMU for an estimated 10 hours, using them throughout whole training sessions will not be an issue.

	LPMS-B	LPMS-B OEM
Size	45x37x20 mm	28x20x12 mm
Weight	34 g	7 g
Bluetooth	2.1 + EDR, 2.412 - 2.484 GHz	
Communication Distance	< 18 m	
Orientation range	360° about all axes	
Resolution	< 0.05°	
Accuracy	< 0. 5°(static), < 2°RMS (dynamic)	
Accelerometer	3-axis,± 20 / ± 40 / ± 80 / ± 160 m/s², 16 bits	
Gyroscope	3-axis,± 250 / ± 500 / ± 2000°/s, 16 bits	
Magnetometer	3-axis,± 130～± 810uT, 16 bits	
Pressure sensor	300～1100hPa*	
Data output format	Raw data / Euler angle / Quaternion	
Sampling rate	0～300 Hz	
Power Consumption	290 mW @ 3.3 V	
Power supply	Lithium bat. > 10h (3.7 @ 800mAh)	
Temperature range	-20 ～+60°C	-40～+80°C
Connector	Micro USB, Type B	

Fig. 2. LPMS-B IMU specifications

2) High-FPS Video Camera

The high-fps camera used in the system is a GoPro Hero3 Black Edition Action Camera [6]. Even with its miniature size, it can record high frame rate video without compromising video resolution.

The GoPro Hero3 also as a built-in Wi-Fi module used to connect to the camera and control it wirelessly. Originally intended to be used and even worn in extreme sports, its portability is key to maintaining ASSESSOR's mobile profile.

3) Android Tablet

The Android tablet currently used in the system is an ASUS Nexus 7 (2012) [7]. At the time of purchasing equipment back in late 2012, the Nexus 7 was one of the top-performing Android tablets available in the market. It has both Bluetooth and Wi-Fi which it uses to communicate with the IMUs and GoPro camera.

B. Methodology

The process of using ASSESSOR is a cycle as seen in Fig. 3 in which the end product is the necessary course of action after reviewing and analyzing the motion and video data. It can affirm things correctly being done by the athlete or things being taught by the coach that work in improving the athlete in which the necessary course of action would be to continue and even improve on them. On the other hand, it can also identify errors in the athlete's performance or the coach's current methods are not working on the athlete. With that, the necessary course of action would be to correct or change them. Once the necessary courses of action have been identified, the whole process can be repeated to monitor the next performance.

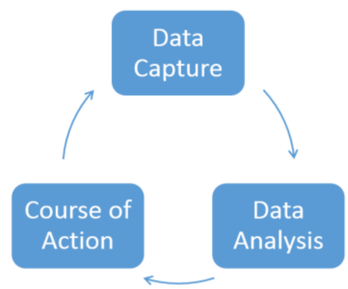

Fig. 3. ASSESSOR cycle

1) Setup

Setting up the system is simple so that ASSESSOR's integration into a team's sports program is not a hassle. Just connect the tablet to the IMUs and camera, attach the camera to a tripod, place the tripod to the desired location, attach the sensor to the athlete, and calibrate the IMUs. After that, there are a few pieces of information that just need filling up within the Data Capture screen, and the app is ready to record the performance.

2) Data Capture

Capturing the performance is simple. A press of the "Start" button commands the ASSESSOR app to record the IMU data and tells the camera to start recording as well. The app plays a sound simulating a gun start in track and field to signal to the athlete the start of the recording. Once the performance is done, a press of the "Stop" button halts the recording from both IMUs and GoPro.

The IMU data is stored in a comma-separated value (.csv) file with a file name obtained through the information filled earlier along with the date and time. The .csv files are organized in a folder structure in the tablet using the same filled-out information for easy access.

The IMU data recording is at 50Hz or every 0.02 seconds while the camera is recording at 50fps at 720p resolution to have a one-to-one correspondence between IMU data and video data. Although the GoPro can record at a faster frame rate, the ASSESSOR app performed better at 50Hz compared to higher sampling rates probably due to the app not having optimized or efficient code, the Nexus 7 not being able to handle the load, or both.

3) Data Analysis

Before proceeding with analyzing the data gathered, the video data must be obtained from the GoPro either by using the official GoPro app [8] to download the video wirelessly or by reading the camera's micro SD card through a USB on-the-go cable and a memory card reader attached to the Nexus 7. Once the video has been obtained, data analysis can now proceed through the Data Analysis screen.

In the Data Analysis screen, there are two spaces to input both the .csv file location and the video data location. These can easily be filled up by selecting the files through the integrated file browser. Once a specific data set has been selected, a press of the "Analyze" button will take those data and present it with the IMU data graphically presented along with the synchronized video data. The coaches and athletes can then proceed in viewing the performance and learn from the data.

4) Social Sharing

If there are parts of the synchronized data that the coach or athlete would like to share, the dedicated screenshot button is present to save a screenshot on the tablet. Aside from that, a selection menu will appear that will allow the said screenshot to be shared onto social media as well as email and into the cloud.

III. System Creation and Features

ASSESSOR is made from various tools, open source libraries, and pieces of code freely found online [9-15]. For example, the User Interface or UI was made using the Android Developer Tools (ADT) [9] while an icon set was taken from icons8.com [10] to have a uniform and appealing interface.

A. Data Recording

The data recording portion of the app is a modification of the source code provided by Life Performance Research, Inc. [5]. The source code provided enabled the viewing of the data stream from a single IMU and was missing a way to record it. With the current modifications, the app can view and record from up to three simultaneous IMUs.

1) Sensor Calibration

In order to have data that is easier to understand, a reference point or position must be set. Inside ASSESSOR is a "Calibrate" button that is pressed when the athlete with the sensor is at a resting position to make the current orientation of the IMU the reference position. This reference calibration is mainly for the purpose of making the current orientation as (0, 0, 0) with the values ranging from -180 to 180 degrees.

2) Hardware Interaction

While communication between the tablet and the IMUs was easy thanks to the source code aforementioned, a way to communicate with the GoPro through ASSESSOR had to be made. The functions of the official GoPro app had to be mimicked so that they could be integrated into ASSESSOR to achieve simultaneous recording. Thanks to the GoPro users' forums [11] and a certain GitHub repository [12], we learned that the commands the official GoPro app sends to the camera were simple HTTP commands and that these commands were listed down in the aforementioned forums. Through the repository, we were able to successfully integrate the GoPro app's "Start Recording" and "Stop Recording" commands into the "Start/Stop" button of ASSESSOR.

After some testing of the recording capabilities, we noticed that the camera recording started later than the IMU recording even though both record commands were sent at the same time. Since this delay from the camera is most likely inevitable without modifying the camera itself, we put a delay on the IMU recording to coincide with the start of the video recording.

3) Min/Max Values

In the Data Capture screen, once a record of a performance is done, we can immediately see the minimum and maximum values of each axis of each type of data the IMUs stream to the tablet even before loading up the data set into the Data Analysis stream. This is useful for more immediate feedback on the performance.

B. Data Analysis

The data analysis portion of the app is also built from multiple open source libraries and code such as a CSV library to read the recorded IMU data [13], a file browser app that can be accessed through another app [14], and a graphing/charting library to visualize the IMU data [15]. Those mentioned, along with some ADT Application Programming Interfaces (APIs), were combined to deliver an interactive analysis screen that is simple and intuitive to use for the end-user.

Data analysis can either be solo for one data set, or comparison for two data sets. In comparison, it can either be a comparison of two different data sets from the same athlete, or a comparison of the data sets of two different athletes.

1) Solo Analysis

The Solo Analysis screen as shown in Fig. 4 was designed to simultaneously display the graphical visualization of the IMU data and the corresponding frame of the selected sample. This was done in order to easily relate the IMU data with their corresponding motions through the video data. Without the video data, understanding the motion data graphs would be more difficult.

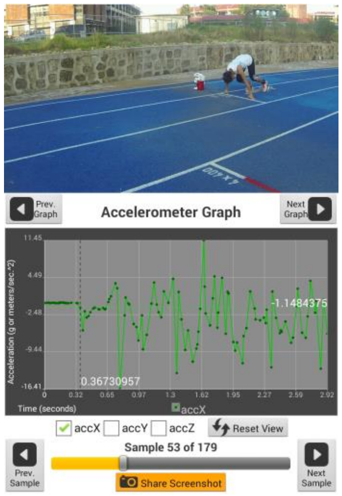

Fig. 4. A solo analysis screen analyzing an athlete's reaction time (accelerometerX in g's vs time in seconds). IMU and video data are synchronized with sampling controlled by a seek bar and two buttons at the bottom for quick and fine control, respectively. Another set of buttons at the middle control which type of data from the IMU to display. Also, the graphs have pan and zoom capabilities along with the ability to isolate axes through checkboxes.

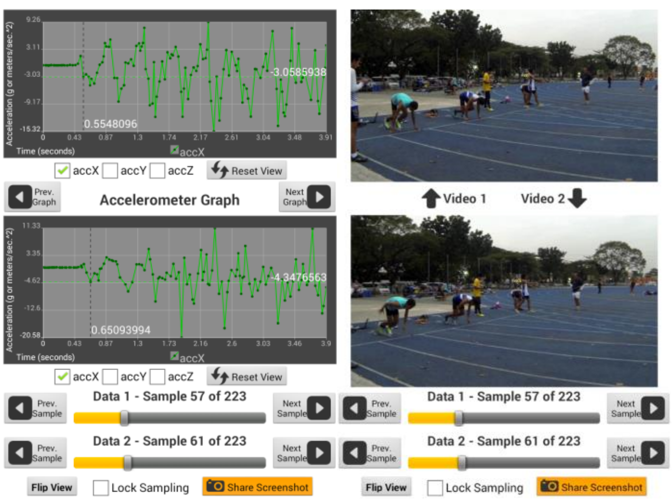

Fig. 5. A comparison analysis screen measuring the reaction time of two different athletes. Features are the same as the solo analysis screen except with videos on top of each other and graphs the same as well. The switching between videos and graphs is through a "Flip View" button at the bottom. Additionally, a "Lock Sampling" checkbox is available to move both data sets at the same time.

2) Comparison Analysis

In working with two data sets for comparison analysis using the same seven-inch screen, a different approach had to be done in displaying two graphs and two videos. As shown in Fig. 5, we decided to put both graphs on top of each other with the two videos on top of each other as well on another screen which can be accessed through the "Flip View" button. That way, the two graphs can be compared with the video frames easily accessible for quick reference.

C. Data Sharing

An important feature of ASSESSOR is the ability to share the data, being in a digital format. Compared to hand notation and a coach's verbal feedback through memory recall, the performance data is now easier to share. Coaches do not need to heavily rely on their memory to convey their assessments to their athletes. Additionally, athletes can easily obtain a copy of their own performances for them to study on their own. That way, the learning of the sport extends outside of training.

1) Screenshot Button

In both Solo Analysis and Comparison Analysis, there is a "Share Screenshot" button as seen in Fig. 4 and 5. At any point in the analysis, if there is a sample in the data that needs to be shared, a press of that button would instruct ASSESSOR to save a screenshot inside the folder of whom the data is from. A pop-up menu would then appear to ask where the screenshot would be shared, whether email, social media, or to the cloud.

2) Sitedrop Integration

With screenshots already being saved into the tablet, we also integrated a service called Sitedrop [16]. What Sitedrop does is it automatically creates an interactive website out of a single folder from Dropbox [17]. With all performance data organized in the tablet in a single folder with the corresponding subfolders, we used a Dropbox synchronization app [18] to mirror the contents of the performance data folder to a corresponding folder in Dropbox. That folder, containing the .csv files, the videos, and the screenshots, is then read by Sitedrop to create a gallery website complete with navigation, favorites and commenting, and password protection as seen in Fig. 6. This takes out the hassle of manually uploading the data by automatically creating a medium to discuss the performance data among a select group of people, like a team and its coaching staff.

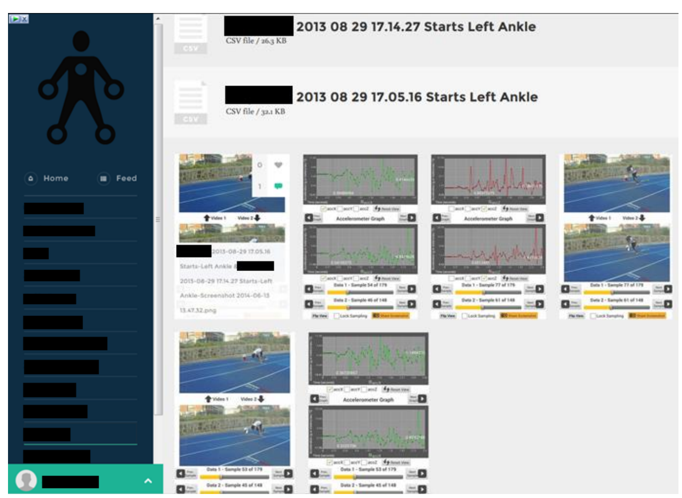

Fig. 6. A Sitedrop-created website showing thumbnails and .csv files with the site's navigation on the left side

IV. Experiments

The experiments conducted using the system were in, but not limited to, track and field and basketball. These experiments demonstrate how ASSESSOR works in gathering and analyzing sports performance data.

A. *Sprint Block Starts Reaction Time*

In order to get an athlete's reaction time on the starting blocks, we reproduced the method used by an app called sprintStart [19]. By attaching an IMU to the athlete's starting leg, specifically the ankle, the IMU would register a spike after a relatively flat start indicating a quick movement from the starting leg, signifying the reaction to the gun start played by the ASSESSOR app at the start of recording. This spike would then be an estimate of the athlete's reaction time.

The experiment was done twice with the same athlete to compare the athlete's reaction time from two separate trials.

B. *Basketball Spin Move Rotational Speed*

In basketball, one of the fundamental ways to evade the defense while with the ball is to do a spin move. One of the requirements of a spin move in order to successfully get past the defense is speed. In this experiment, we attached an IMU to the torso of an athlete to measure the peak rotational speed of the athlete's spin move.

C. *Results and Discussion*

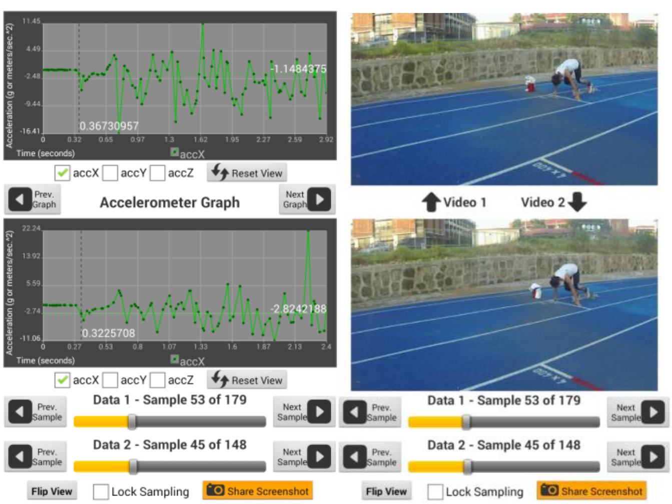

Fig. 7. Comparison analysis of two trials testing for sprint reaction time

Loading the two sets of data from the two trials for the sprint reaction time comparison analysis as shown in Fig. 7, it can be seen that in the first trial on top, the graph started to spike at around 0.37 seconds indicating a reaction time of the same amount. Comparing it to the second trial at the bottom, it can be seen that the second trial had a faster reaction time of around 0.32 seconds.

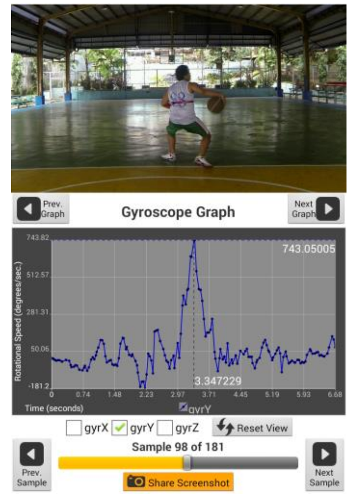

Fig. 8. Solo analysis of a trial testing for the peak spin move rotational speed

Loading the data set for the basketball spin move solo analysis as shown in Fig. 8, it can be seen that the peak value during the spin move was at around 743 degrees per second.

These two experiments demonstrate how the system helps gather performance data, especially quantified data that cannot be gathered by watching the athletes alone.

D. *Other Experiments*

Many other experiments in track and field and basketball have been conducted using ASSESSOR but were not discussed here. These include experiments on crossover quickness in basketball as well as experiments on torso leaning and swaying, arm swings, and step frequency for track and field.

V. Social Impact

Through ASSESSOR's screenshot-sharing capability as well as the integration of Sitedrop, performance data of individual athletes now become social. Coaches can easily consult with peers with data that they can present. Athletes, on the other hand, can further discuss and give constructive criticisms to their fellow athletes now that their performance data are easily uploaded online as shown in Fig. 9. They can even use the data as bragging rights and engage in friendly competition with each other now that they have quantitative performance data.

With the uploaded data, athletes and coaches can easily interact outside training time and without the need for physical proximity. Having data that they could discuss and compare will help them in pushing each other in improving their performances. Now, everybody in the group can easily have a say in an athlete's performance.

Fig. 9. Facebook discussion among Ateneo de Manila track and field athletes on the performance of a fellow athlete

VI. Conclusion and Other Applications

In conclusion, we have developed a system using a combination of wearable inertial measurement units, a high-fps camera, and an Android app and tablet that records and visualizes synchronized motion data and video data to assist coaches and athletes in evaluating their performances and finding actionable data. Additionally, the data can easily be shared online to continue discussions outside of training and to have a bigger discussion group compared to the usual one-on-one verbal conversation between a coach and an athlete.

ASSESSOR is not only limited for use in capturing and analyzing sports performances but is applicable to motion analysis in general. One such application would be monitoring the progress of patients undergoing rehabilitation [20]. With the recorded data, doctors and physical therapists can easily compare the current condition of a patient with their previous data. On the other hand, patients will be able to easily see their own progression, which can help motivate the patient throughout the rehabilitation program. With the system, discussions and consultations between doctor and patient can continue online through telerehabilitation.

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