Swinging with IMUs

Javier Hernandez Rivera
javierhe@andrew.cmu.edu

Tomas Simon Kreuz
tsimon@andrew.cmu.edu

Abstract

Understanding if a movement is being executed correctly is important to a number of manipulation tasks. We present a preliminary study using inertial measurement units (IMUs) to evaluate the correct execution of squash swings, as well as discriminating them from similar racquet sport swings such as tennis and badminton. Additionally, we will show some preliminary results that suggest that it is possible to detect at what point in time the movement was done incorrectly and why.

1 Introduction

Understanding if a movement is correctly executed is of paramount importance to a number of manipulation and locomotion tasks. Some examples include coaching (e.g. to ensure good form in sports [1] and rehabilitation exercises), health monitoring (e.g. post-stroke mobility and pain assessments), and ”signature” based failure detection in manufacturing processes.

For this study, we will focus on assessing whether a squash swing is correctly executed or not. We will present a preliminary study on using mainly accelerometer data collected with inertial measurement units (IMUs) placed along the squash player's arm and on the torso (see Fig. 1).

Previous work in the analysis of racquet movements has used high-speed cameras and manual annotations and tracking of visible markers. Motion capture systems have also been used to characterize tennis swings [3]. See [2] for a review on applying scientific analysis to the major racquet sports. In [4], the kinematics of an elite squash stroke were analyzed in detail and we recommend this thesis as an in depth analysis.

2 Squash Swing

The purpose of this document is not to provide a guide or tips for a better squash stroke. Nonetheless, we will outline some mistakes that we will want to capture and hopefully detect.

We will limit ourselves to discussions of a standard straight forehand shot. One typical mistake is incorporating extraneous wrist movements—in squash, the wrist is supposed to be kept cocked and fairly static throughout the stroke. Another mistake is keeping the upper arm too far away from the body. In contrast to tennis, there is often not enough space in squash for a large windup, so speed is generated in a downswing by keeping the racquet close to the body. Trunk rotation and shoulder rotation then contribute to creating the necessary speed in the correct direction [4].

A fairly popular explanation for how force is generated in racquet sports (and also throws as in baseball) is by propagation across links in the body (e.g. leg to hip to shoulder to arm to wrist), and there is some numerical evidence to support this view.

Ideally, the data collected from the IMUs will allow us to analyze some of these explanations by taking concrete measurements of velocities at each of the joints.

3 Data Collection

The IMUs used were four 3DM-GX1® from MicroStrain® which were placed on three locations along the arm (see Fig.1): on the upper arm, on the forearm close to the the wrist, and on the back of the hand. An additional IMU was affixed on the torso at the sternum. The devices were attached as rigidly as possible (without interfering with mobility) using velcro strips and a latex glove.

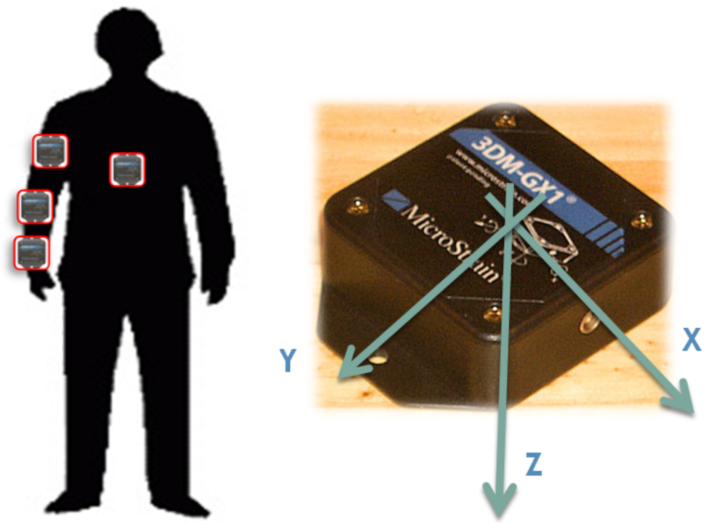

Figure 1: Left, IMU placement. Right, the 3DM-GX1®.

Data was collected for one subject at an intermediate level in both squash and tennis. In addition to a set of calibration motions, the subject was asked to perform the following actions:

- 13 properly executed squash swings (without ball)
- 3 instances with incorrect wrist movement
- 3 instances with interrupted movement
- 3 instances with over-extension and overly separated upper arm
- 4 badminton swings
- 4 baseball swings
- 5 tennis swings

The IMUs provided readings at a sample rate of 100Hz. Data available were instantaneous triaxial accelerometer, magnetometer, and gyroscope readings, and a stabilized absolute orientation quaternion used for visualization of the relative joint orientations and for the velocity calculations.

4 Experimental Setting

In this section we aim to gather some insights in the manipulation task of squash swing. First, we want to determine wether is possible to automatically differentiate good squash swings from bad swings. Second, we would like to test if it is possible to determine exactly what part of the movement was done incorrectly and which part was done correctly.

4.1 Alignment

To be able to reliably compare the data from different swings, the signals must first be aligned across time. We used Dynamic Time Warping (DTW) using the accelerometer readings with respect to a reference swing. This provided a correspondence at three manually labeled keypoints on the reference swing: the start of the movement, the point where the racquet has been fully swung back, and the end position after completing the forward motion of the swing (see Fig. 2.) The signals were resampled using linear interpolation between these keypoints to make the temporal extent match that of the reference swing. [1]

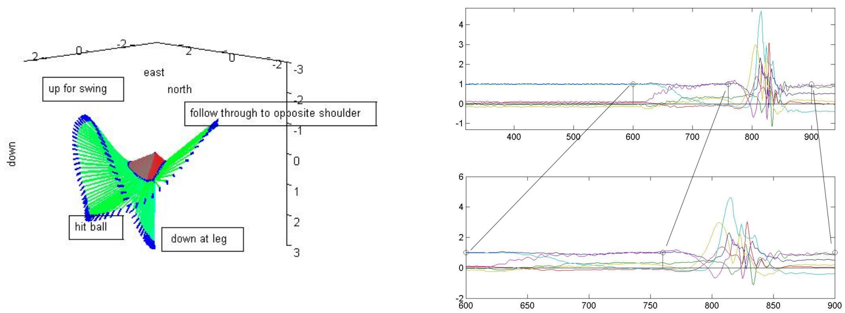

Figure 2: Alignment. Left, 3D visualization of the arm trajectory with marked keyframes. Right, top, keyframes in reference sequence. Right, bottom, a newly aligned sequence.

4.2 Feature representation

The signals were split into chunks of 10 samples or ${}^{1}/_{10}$ second. Only the accelerometer readings were used for classification (the magnetometers provide orientation with respect to the magnetic north which is irrelevant for this task, the gyroscopes were not used for simplicity).

4.3 Classification

An SVM classifier with Radial Basis Function kernel was used. Performance was evaluated using 5-fold cross-validation, and the hyperparameters C and gamma were tuned using 5-fold cross-validation on the training set in each training round. Given the constraints of our data collection (ie. one subject), the problem of detecting good squash swings turned out to be very easy and we obtained 100% accuracy.

In most real manipulation tasks, there exists a series of necessary steps to obtain a successful outcome. Because of this, it is necessary to detect as soon as possible any deviation from the correct movement. Fig. 3 illustrates the predictions of the classifier for a particular set of movements. As it can be seen, the classifier generates a prediction every ${}^{1}/_{10}$ second and these are strongly correlated with the effects of each movement. For instance, the middle graph corresponds to a squash swing in which the arm is extended further from the body than usual and, therefore, it is considered a bad swing. We can see that the classifier predicts bad movement (red rectangles in the bottom graph) when the angles of the upper arm differ from those of a good swing (left graph). The graph on the right corresponds to a squash swing with a bad wrist position. We can see that again the algorithm detects the time-points when there is unexpected movement.

5 Visualization and approximate kinematics

To visualize the movements, the stabilized quaternion orientations from the IMUs were used. We will assume that the IMUs are rigidly attached to each link on the arm. We can therefore model the arm as a 3 bar linkage, where, at each joint, the orientation is given by the IMU orientation. To account for misalignments when placing the IMUs on the arm, a set of calibration movements was recorded. [2]

[1] Some iterations of gradient descent on the sum of squared differences of the accelerometer readings were used to improve the locations of the keypoints after DTW.

[2] In practice, the calibration procedure employed did not yield better results than not calibrating.

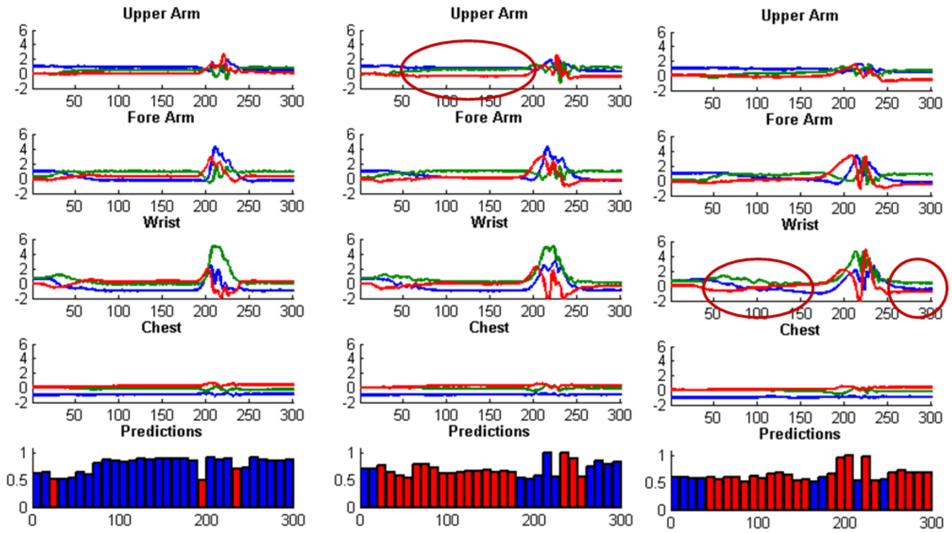

Figure 3: Predictions. Left, good squash swing. Center, interrupted squash swing. Right, squash swing with wrong wrist position. Top, accelerometers of the IMU located on the hand. Bottom, predictions made by the classifier (red - bad squash swing, blue - good squash swing) as well as their confidence values.

Although very approximate, this gives us a way to visualize in 3D the arm position at every step of the swing or stroke. By calculating the trajectories of points on the arm, we can compute an approximation to their linear velocities (with respect to the torso). This is shown in Fig. 4. We caution that we had no way of evaluating the validity of these estimations, but the values are not far off from those reported in [4]. The increasing values of linear velocity reflect the "kinetic chain" concept, where each link increases the velocity and strength imparted at the final link.

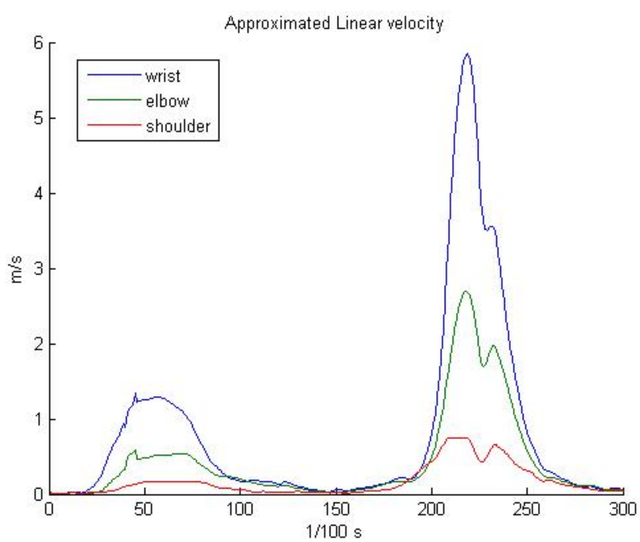

Figure 4: Approximate magnitude of the linear velocity profile with respect to the torso for a typical squash swing, at points on the wrist, elbow, and shoulder. The first bump on the left is the movement from the resting position to a prepared squash stance.

6 Conclusions

The IMU measurements used captured enough information to distinguish the good and bad swings that we had collected. From this preliminary study, we have realized that we would need a more realistic data collection to be able to draw conclusions.

Also very desireable would be a clean way to obtain an accurate estimate (and validate it somehow) of the 3D position of the arm joints at every moment in time. Although the information that we were able to extract was good enough for visualization, we do not have a way of quantifying its accuracy (but we suspect it to be poor).

In any case, the results that we have obtained, even with such limited training data, are very promising. We believe that automatic coaching would indeed be possible, and it would be worth it to investigate if this can be done with a system of lower cost than the one used here.

References

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