IMU ACCELERATION DATA DIFFERS BETWEEN THE FRONT AND REAR FOOT IN SNOWBOARD HALFPIPE

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The purpose of this study was to compare acceleration data from front and rear foot IMUs of elite snowboard halfpipe riders to gain insights towards IMU driven motion analysis and event detection. Utilizing IMUs attached to riders' boots, the research found varying time offsets and correlations across different axes. The findings show that IMU placement and orientation play a crucial role in accurately capturing snowboarding dynamics. The study contributes to the potential use of IMU data for enhancing motion analysis and feedback systems in snowboard freestyle.

KEYWORDS: board sports, elite athletes, sensor technology, time series

INTRODUCTION: Inertial measurement units (IMUs) are widely used in sports science to gain insights in sports equipment or human motion and often serve as basis for movement analysis and real time feedback systems (Kranzinger et al., 2023). Specifically in snowboard freestyle, Harding et al. (2007) already presented an approach to extract performance related parameters using body mounted IMUs at the lower back. As the movement of the board characterizes a trick in snowboard freestyle (International Ski and Snowboard Federation, 2022) and the contact between snow and board defines the airtime (Harding et al., 2007), the authors assume that an IMU placement close to the board without interfering the riders' natural riding routines provides important information about the performance. The snowboard surface is used for grabs during tricks and to stand on it in-between runs. That's why the binding/boots are ideal as a place close to the board with a fixed connection to the board. In light of the force measurement studies by Kersting et al. (2022) and McAlpine et al. (2012), it remains unclear whether it is necessary to use an IMU on each foot or if a single IMU on one foot is sufficient. Especially, because riders can change their riding direction during a run, known as switch and forward riding. Additionally, the snowboard cannot be regarded as rigid system due to the flex. Therefore, the objective of this study was to evaluate the differential impacts of IMU data from the front and rear foot across each spatial axis to potentially optimize sensor placement or suggest sensor fusion (Bancroft & Lachapelle, 2011) and improve motion analysis accuracy in snowboard freestyle..

METHODS: Two elite snowboard freestyle riders (1 ♀, 1 ♂; age: 17.0 years; mass: 62.7 – 67.3 kg; height: 172.0 – 177.6 cm) of the German National Team performed 129 snowboard halfpipe tricks in a competition ready superpipe (Kitzsteinhorn, AUT). In each run, riding in their normal stance only, riders did 4 - 6 hits with trick-specific 180° - 900° rotations in randomised order. Only successfully landed runs were analysed. The study was conducted in accordance with the Declaration of Helsinki and procedures were approved by the Regional Ethics Committee (number of approval: 214/2022). Runs were recorded by two IMUs (Shimmer3 IMU Unit, Shimmer Wearable Sensor Technology, Dublin, Ireland) at 201.03 Hz and filmed by a video camera (Panasonic HC-X1500E, Panasonic, Kadoma, Japan) capturing at 100 Hz for protocol purposes. The two IMU devices were strapped to the respective lateral boot side above the ankle strap aiming for an identical axis orientation in neutral stance. Data were stored on an internal storage and synchronized with each other by manual tapping on the IMUs, recorded in the video. The coordinate directions of the rear IMU were adjusted to those of the front IMU by a 180 degree rotation around the x-axis to ensure comparability leading to a coordinate system with the x-axes being the top/bottom, the y-axis being the toe/heel, and the z-axis representing the nose/tail direction of the board.

Normalized cross-correlations of complete halfpipe runs were calculated axis by axis between the two IMUs. Analysed were: a) the temporal offset (lag) of the optimal correlation of front and rear IMU signal with respect to synchrony for each axis and b) the cross-correlation values at sensor synchrony (no lag). All three spatial acceleration data axes (wide range: ±16 g) of the IMUs were examined separately. Analysis were performed using Python 3.9 enriched with libraries such as NumPy for handling numerical data, Pandas for efficient data manipulation, and Matplotlib for visualizing the results.

RESULTS: When visualizing the cross-correlations for each run and spatial axis, a general characteristic was observed for each spatial direction over all runs. Examples for a single run are presented in Figure 1.

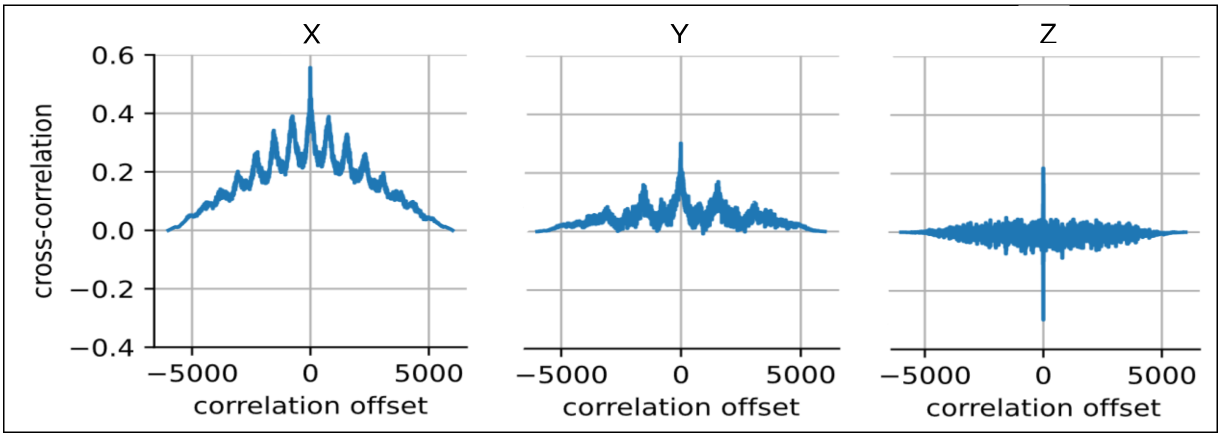

Figure 1: Exemplary cross-correlation of a single run for each spatial IMU axis featuring lags of -8 frames (x- and y-axis) and 0 frames (z-axis).

The components in the x-direction showed the most pronounced course of the cross-correlation, which was exclusively positive in this IMU direction and had a symmetrical, oscillating and increasing characteristic in the direction of the correlation offsets' zero point. The cross-correlation for the y-accelerations, which in some respects also reflect the oscillating characteristic of the x-component, featured the least pronounced characteristic while the z-component featured an additional impact due to both positive and negative cross-correlations. The cross-correlations in Figure 2A indicate that features on the x-axis had a negative median offset of -7 frames, with an interquartile range (IQR) of 1 frame.

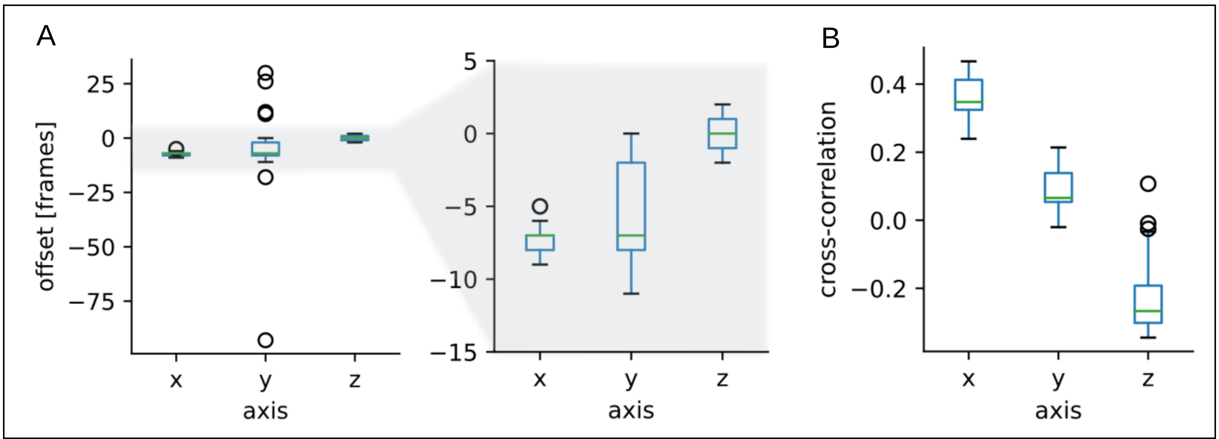

Figure 2: Distribution of A) the cross-correlation offsets for each IMU axis, overall (left) and zoomed in (right) and of B) the cross-correlation values at sensor synchrony (offset = 0).

For the z-axis, the median offset was 0 frames with an IQR of 2 frames. In contrast, the y-axis showed a wider range of dispersion, evidenced by an IQR of 6 frames, which is particularly evident from the outliers in Figure 2A on the left. The -7 frames median for the y-axis is equal to the x-axis. For the x-axis, the median cross-correlation value at sensor synchrony was 0.35 with an IQR of 0.09, indicating overall positive correlations. In contrast, the z-axis showed a negative median cross-correlation value of -0.27 with an IQR of 0.11 while the y-axis demonstrated a smaller effect at sensor synchrony with a median cross-correlation value of 0.07 and an IQR of 0.09.

DISCUSSION: The expected delay between the rear and front IMU data is not prominent in all axes. The x-axis features the most striking and consistent median delay of 7 frames which translate to about 0.035 seconds. However, the magnitude could depend on the riding speed and style (e.g. flatbase landing vs. 'rolling' from tail to nose). Since the cross-correlation value is positive, with sensor synchrony, top/bottom movements generate time series with a similar characteristic comparing both feet. For example, the impact of a clear landing acts in the same direction. The oscillating characteristic of the cross-correlation could be due to the constant sequence of jumps in similar time windows with the same underlying halfpipe typical acceleration curves as shown in Harding et al. (2007), which when shifted by one jump lead to a similar acceleration time series. The top/bottom movement of the feet seems to have the most similarity in between the both IMUs. This could be because it is the athletes' primary active movement direction when jumping and the abrupt landings induce the highest breaking forces. The clear time offset compared to the other axes could also be due to the fact that the flex of the board allows the most variability in the x-direction.

While the y-axis median time delay equals the x-axis median, the y-axis time offset is the most varying in between both IMUs (IQR = 6 frames; highest scattering of time lags with several clear outliers). Therefore, the same conclusions cannot be assumed. The high IQR value indicates a high independency of the feet's heel/toe edge movements. This can be explained with the torsion of the board which is either actively applied by athletes while steering the board or passively due to torque deforming the board e.g. at landings. Speed checks, which are active breaking manoeuvres by the athlete approaching the next hit, also result in different accelerations as the board not only translates but also rotates around a point with unequal distance to both IMUs. The distinct outliers in of time lags in y-direction however should not be overrated since only slightly smaller magnitudes of cross-correlations are found, which are much closer to synchrony.

The z-axis shows no clear time offset and features mostly negative cross-correlations which can be explained as the flex of the board causes opposing accelerations on the boots in z-direction. The result of no median time offset could be because the board is very stiff in this direction and a movement occurring due to board flex is suspected to show symmetrical characteristics.

The expected time offset was only found consistent for the x-axis which might be the most relevant for use cases like airtime detection. Therefore, for event detection it is important to know if the data is retrieved from the front or rear foot. For example, the detected airtimes could be off by the described 0.035 seconds just because of the offset. Therefore, it would induce an error of at least 1.7% when looking at current airtimes of top level halfpipe athletes (Merz & Gorges, 2023) and would be even of higher magnitude for young athletes with lower airtimes. The signals from the IMUs are mitigated by the interaction between the binding, boot, and strap, potentially leading to signal noise. Future works should also consider different IMU synchronizations. Here, synchronization was performed manually which can potentially result in slight discrepancies in data accuracy. The frequency difference of the IMUs and the video results in a potential systematic error of ±2 frames for the synchronisation of both IMUs, which however, cannot explain the presented lags completely. Also, the variability in strap positioning can affect consistency as the IMU axes cannot be guaranteed to align perfectly. A more precise measurement can possibly be achieved by attaching the IMUs directly to the board/binding. Furthermore, IMU drifts can influence the results. Another limitation of this study is the homogeneity of the participant pool, as the riders are all from the national team, which implies a similar skill level among the subjects. A higher skill variation leads to a more variable riding speed and style which then again is expected to lead to more varying acceleration offsets. Additionally, the low number of subjects (n = 2) should be noted as a limitation. However, in

this study, this is statistically mitigated by the high number of analysed tricks (n = 129). The transferability of the data presented, which is specific to halfpipe, to other snowboard freestyle disciplines is in regard to riding and jumping (Big Air competitions and jump features on Slopestyle courses) to be expected due to comparable movement patterns and board-snow-interaction. The characteristics of IMU data on Slopestyle features like rail obstacles however require separate consideration, as more localized forces act on the board in these contexts.
Future studies should further focus on analysing the time lag in relation to specific, practical snowboarding manoeuvres such as take-offs and landings, and could also expand beyond solely targeting acceleration to include other IMU-based data like angular velocity, angular displacement, and magnetic field orientation. This would provide more targeted insights for feedback training and event detection during these critical moments. Thereby, different information of the front and rear foot sensors can be beneficial in providing deeper insights into the riders' interaction with the board. An intriguing aspect for future research is the comparative analysis across board sports. This approach involves assessing the transferability of these findings to other sports using bindings, such as wakeboarding or kiteboarding which could unveil universal principles of board-based sports across various disciplines.

CONCLUSION: Overall, IMUs positioned with a lateral offset in snowboarding deliver similar acceleration characteristics in the x-axis (top/bottom direction) including a general time offset. The measurement data seems to be redundant for simple tasks such as jump detection, but there is much more information available when looking at both IMUs while knowing their location in relation to the direction of riding. Including accelerations from all three spatial axes, this potentially enables more complex detection algorithms e.g. for precise airtimes or biomechanically relevant event times.

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