Vertical Launch Angle Measurement of a Golf Ball Using Audio and Monocular Video Data

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Abstract: In golf, several parameters can be measured that describe how the golf ball was hit and how the ball lifts after impact with the golf club, the so-called launch parameters. In addition to the spin rate or the velocity of the ball and club head, the launch angle is an important value that describes the vertical component of the ball's launch direction. For professional use, there are systems called launch monitors that use either radar-technology, multiple high-speed cameras or a combination of both to measure the above parameters. Despite their high accuracy, these systems can suffer from disadvantages such as some inconvenience regarding size, weight or setup, and an inaccessibility regarding high cost. Therefore we present a method for vertical launch angle measurement based on monocular low frame rate video and audio data, by detecting the motion blur structure created by the launching golf ball. This approach allows the vertical launch angle to be measured with a simple and inexpensive setup that achieves an accuracy of $\pm$ 0.74°, which is comparable to a commercial launch monitor.

1 INTRODUCTION

In golf, there are different types of ball flights used in different situations on the golf course. They are determined by different parameters and characteristics of the golf swing and the way how the ball is hit. The most important parameters are the launch parameters, which describe how the ball lifts off after impact with the golf club. The most common launch parameters are listed and described in Table 1. With these parameters it is possible to calculate the outcome of the golf swing regarding the trajectory of the golf ball.

While learning the golf swing or training for different ball trajectories a numerical feedback on these launch parameters can be helpful to build consistency and confidence in different situations on the golf course. In addition, certain combinations of launch parameter values can be used to detect mistakes during the golf swing. The commercial solutions for this type of ball flight measurement are called launch monitors. They come in a wide variety of price and accuracy levels, using photometric-based systems, radar-based systems, or a combination of both.

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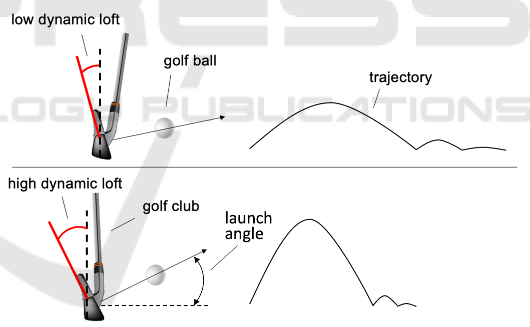

Figure 1: Visualization of a golf ball trajectory using a low and high dynamic loft.

The radar-based systems, for example Trackman 4 (Trackman A/S, 023a) and Flightscope Mevo+ (FlightScope Mevo LLC, 2023), measure the movement of the ball and club in three-dimensional space, using the Doppler effect. By emitting radar waves and measuring the reflection it is possible, for example, to determine the speed of an object or the ball spinning rate (Tuxen, 2010). This technology allows to track a golf ball up to a distance of 365 meters (TrackMan A/S, 023b).

The photometric-based systems, for example GC-Quad (Optimum Golf Technologies Ltd, 2023) and Syktrak (GOLFTEC Enterprises LLC, 2023), are using a set of high-speed cameras working at up to

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Table 1: Launch parameter overview (Johansson et al., 2015).

Launch parameters	Description
Club head speed	The velocity of the golf club head at impact.
Face angle	The alignment of the golf club face relative to the target direction.
Swing path	The direction of the club movement relative to the target direction at impact.
Angle of Attack	The vertical component of the club movement at impact.
Ball speed	The starting velocity of the golf ball after impact.
Dynamic Loft	The vertical alignment of the club face at impact.
Vertical launch angle	Angle of the ball flight direction relative to the horizon.
Horizontal launch angle	Angle of the ball flight direction relative to the target direction.
Spin Rate	The Rotation of the golf ball per minute after impact.
Spin Axis	The tilt of the spin axis after impact.

10.000 frames per second, to capture the movement of the ball and the club at impact from different angles. By detecting the ball and its movements in the first few milliseconds of the ball flight, it is possible to calculate, for example, speed, spin rate or direction (Kiraly, 2005).

One can divide the launch parameters into two different categories: Firstly, the ball related parameters, such as launch direction, ball speed, spinning rate. Secondly the club related parameters, such as dynamic loft, angle of attack or club face angle. (Leach et al., 2017) shows that in comparison with an 3D motion capturing system, even though the two mentioned measurement methods are completely different, the measured ball related parameters of both systems are highly consistent with each other.

One of the most important ball related parameters is the launch direction, which can be represented by horizontal and vertical components. While the swing path and the club face angle are mainly determining the horizontal component, the vertical component is mainly determined by the angle of attack and the dynamic loft at impact. (Wood et al., 2018)

By adjusting the dynamic loft, different vertical launch angles can be achieved. Referring to Figure 1 it can be seen, that by reducing the dynamic loft, the vertical launch angle is also reduced. This, in combination with a constant club head speed, results in a significantly lower ball flight height and an increased distance the ball rolls on the ground. On the other hand, a higher launch angle results in a higher ball trajectory and a shorter roll distance. Both flight trajectories can be useful in different situations regarding obstacles on the golf course and are crucial for achieving a low number of strokes.

When training to achieve a specific vertical launch angle, a launch monitor can be helpful. Even though the introduced commercial launch monitors can achieve a high accuracy of $\pm 0.3°$ using radar-based systems and $\pm 0.1°$ using photometric systems (Leach et al., 2017), they suffer from certain disadvantages, depending on the systems used. In addition to some inconvenience due to size, weight, or setup, most launch monitors require an additional device, such as a smartphone or tablet, to display the measurements. Also, the high cost (up to ~20.000 $) doesn't make them suitable for amateur and beginning golf players.

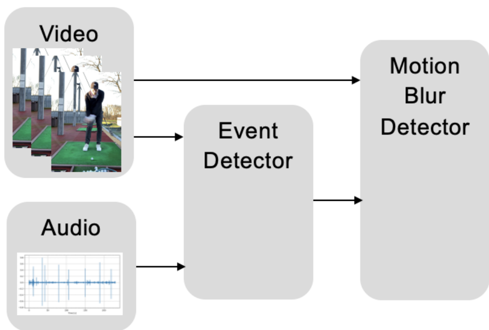

Figure 2: Diagram of vertical launch angle measurement.

Therefore, we present a new method for vertical launch angle measurement using only a monocular low frame rate video in combination with the audio data, as shown in Figure 2. The vertical launch angle measurement is performed by detecting the motion blur created by the launching ball after impact.

Our approach leads to a simple and convenient set up (shown in Figure 7), allowing to work with only one device, such as a smartphone or tablet. Additionally, the video data of the golf swing can be recorded for further analysis, which has been shown to have a positive impact on learning progress (Guadagnoli et al., 2002).

2 METHODS

2.1 Swing Detection

To detect the launch angle of a golf ball after club head impact from video data, the first task is to detect in which frame of the video the impact occurred. In contrast to a method based on ball or club tracking (Chotimanus et al., 2012; Zhang et al., 2020), where either the golf ball or the club is observed to detect a swing, we developed a method using the combination of video and audio data of a recorded swing sequence to detect an impact.

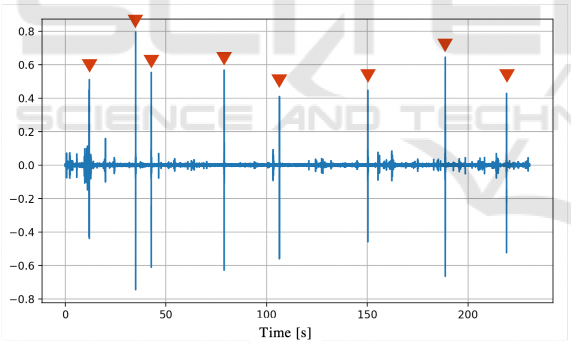

Figure 3: Audio data of a recorded training sequence in time domain.

Looking at the audio data in the time domain (Figure 3), we can detect peaks that indicate that an event has occurred, such as the impact. The detection of a peak is done by searching for a maximum value between a rising and falling flank, using a threshold value calculated according to (1), where $x(t)$ is the audio signal in the time domain.

Using the peak time t_{event} and the video data frame rate fps we can calculate the exact frame f_{event} including the event, which created the mentioned peaks in the audio signal, according to (2).

$$threshold = \max(x(t)) * 0.25 \qquad (1)$$

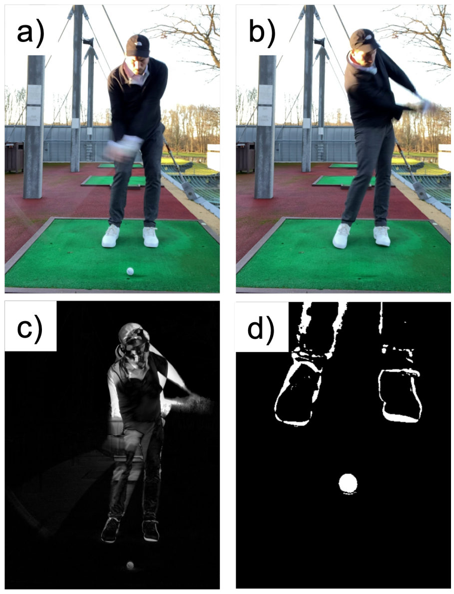

Figure 4: Visualization of ball detection: **a)** 3 frames before impact frame , **b)** 3 frames after impact frame, **c)** grayscale image of the absolute difference between a) and b), **d)** cropped and binarized image of golf ball.

$$f_{event} = \lfloor t_{event} * fps \rfloor \qquad (2)$$

However, the detected peaks can also be caused by different events, such as a practice swing where only the swing movement was done without the intention of hitting the ball, while the sound event was caused by hitting the ground, an impact of a different player or other non-specific sounds.

To increase the confidence that a real swing occurred at the audio-based detected moment of impact, we further examine whether a golf ball left the scene at the detected frame. Therefore, we subtract the frame a specific time before and after the detected impact frame from another as shown in Figure 4 a)-c).

To reduce the probability of occlusions in the assumed area where the golf ball is located caused by the club itself, the frame difference from the impact frame at 60 fps is set to 3. That is, if an impact is detected in frame f_{event}, we subtract the frame $f_{event} - 3$ with the frame $f_{event} + 3$.

In combination with the assumption that the golf ball is in the lower third of the image, it is possible to detect a ball with a particularly high confidence using established computer vision methods. By binarizing the image as shown in Figure 4 c) using a threshold obtained from the Otsu method (Otsu, 1979), a golf ball leads to an explicit pixel structure with a certain roundness and size. Using the Blob Detector from OpenCV (OpenCV, 2023b) on the

Figure 5: Visualization of threshold impact: **a)** threshold = 10 , **b)** threshold = 20 **c)** threshold = 30, **d)** threshold = 40.

resulting image in Figure 4 d), we get the information if a ball is included in the image and further the size and position in pixel values. If the detection of a golf ball is successful, the impact detection is marked as valid, if there is no golf ball included in the resulting image, the detection is marked as false.

In contrast to ball- or club-tracking approach, using audio-event-triggered swing detection, we achieve lower computing time and a independence from possible occlusions of balls, when, for example, setting up for a swing or other arbitrary movements in the scene.

2.2 Launch Angle Measurement

With the resulting information from the swing detection as described above, namely the exact moment when a swing occurred and the ball position in pixel values, we address the problem of measuring the launch angle of the golf ball using monocular video data. Due to the high velocities that a golf ball can reach while playing golf, averaging up to ∼270 km/h (Hahn, Christian, 2017), an exact tracking of the golf ball during flight requires either a high-speed camera or other technologies such as those mentioned in the Introduction section. To solve this problem with a low frame rate camera (60-120 fps), we use the motion blur created by the launching ball in the detected impact frame. The basis for this is a high contrast between the golf ball and the background, which is given by the golf sport itself, using mostly white or yellow golf balls, which are hit either from a green practice mat or grass.

To detect the motion blur caused by the ball, we use a method similar to the one we used for swing detection. Given the impact frame f_{impact}, we created two images f_- and f_+ by calculating the absolute difference between the image frame f_{impact} and frame $f_{impact} - 1$ and also between frame f_{impact} and frame $f_{impact} + 1$. Subsequently, by calculating the addition of these two resulting images f_- and f_+, we get the resulting image where we perform the ball launch detection on. In contrast to the previous method, it is necessary to consider three images due to the low frame rate combined with a lack of synchronization between the moment of impact and the moment an image is recorded. This could lead either to a small motion blur structure in image f_- or to the situation that the ball already left the scene in image f_+.

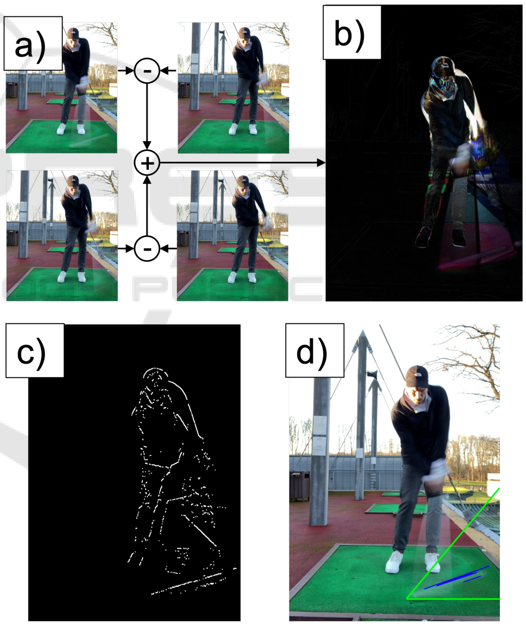

Figure 6: Processing steps: **a)** image subtraction and addition, **b)** result of a), **c)** preprocessed image of b) **d)** result of line detection with ROI.

Combining the information included in the images f_- and f_+, by adding these two images to one another, we increase the probability of detecting the desired motion line, as seen in Figure 5 c).
To separate the motion blur caused by the club from the motion blur caused by the golf ball, we binarize the image with a certain threshold. Looking at each pixel of a grayscale image, we compare the pixel's value with the before mentioned threshold. If the

```
Data: Binary Image I_b, Ball Position P_b
Result: Angle δ
Apply HoughLinesP from OpenCV and
  assign results as list of lines L;
Compute ROI using Ball Position P_b and
  max. angle α =50°;
forall line in L do
  | if line in ROI then
  |   | Compute midpoint m and angle β of
  |   |   line;
  |   | Compute angle γ between m and P_b;
  |   | if D(β,γ) > 3° then
  |   |   | remove line
  |   | end
  | else
  |   | remove line;
  | end
end
Apply RANSAC Algorithm from SciPy on
  resulting list of lines L;
Compute angle δ of resulting line;
```

Algorithm 1: Launch angle detection.

value is below the threshold, the pixel value is set to 0 (black) and if the value is above the threshold, the pixel value is set to 255 (white). Figure 5 shows the effect of different threshold values while creating a binary image. We can observe that by setting a threshold to low (<20), the motion blur created by the club overlays the structures created by the ball (Figure 5 a)), on the other hand if the threshold is too high (>30) it occurs, that the motion line created by the launching ball is erased from the image (Figure 5 d)). The optimal threshold value is observed to be between 20 and 30, as seen in Figure 5 b) and c), the line created by the motion blur of the ball is clearly visible and can be extracted from the image using computer vision methods.

Algorithm 1 describes our approach for detecting the launch angle, based on the binary image I_b, using computer vision methods. First, we specify a region of interest (ROI), which is defined by the ball position achieved from the swing detection (2.1) and an assumed minimum and maximum launch angle, which is shown in Figure 6 d). To improve the line detection using the probabilistic hough line transform from OpenCV (OpenCV, 2023a), we apply a sequence of computer vision methods including a morphological opening, a horizontal Sobel filter and a Canny Edge Detection (6 c)). The following line detection returns a set of lines, of different length and direction. By taking into account the minimum and maximum launch angle condition, and additionally the constraint that an extension of the lines must pass the ball's center position with a defined offset, we can perform a selection of lines that represent the golf ball's line of motion with a high probability. To detect possible outlier, we ran the Random Sample Consensus (RANSAC) algorithm (Fischler and Bolles, 1981) for linear regression using the endpoints of the selected lines.

The resulting line is considered to represent the launch of the golf ball, with respect to the x-axis of the image.

2.3 Experiment

For the evaluation of the presented launch angle measurement approach, we use a radar-based launch monitor, as described in the Introduction section, the Garmin Approach R10 (Garmin Ltd. , Swiss, ~600 $) (Garmin Ltd., 2023). The setup for this is shown in Figure 7, where the camera used for our approach is placed in front of the golf player at a distance of ~2 meters from the golfer. The commercial launch monitor is placed to the left of the golf player at a distance of 2.1 meters from the ball.

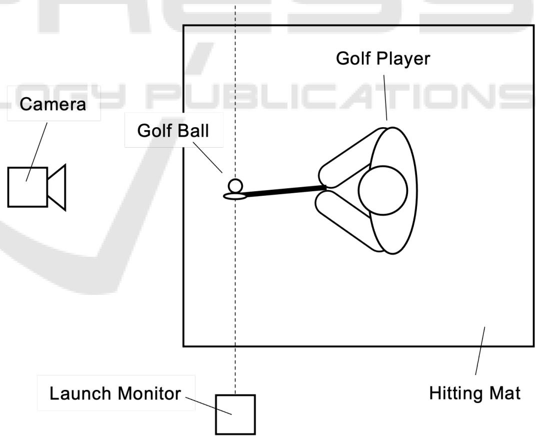

Figure 7: Setup for evaluation.

To compare our approach with the results of the launch monitor, we recorded 41 golf swings with two different frame rates, 60fps and 120fps, while using two different clubs, varying in loft angle and length. The clubs used are a high loft pitching wedge (PW) and a relative low loft 7 iron. The specifications are listed in Table 2.

Table 2: Club specification of ping rapture V2.

Club	Loft angle [°]	Length [m]
PW	45°	0.94 m
7 iron	32°	0.97 m

3 RESULTS & DISCUSSION

As the use of audio and monocular video data to estimate golf launch parameters are underrepresented in the literature, the evaluation of our method is currently limited to a comparison with the results obtained using a launch monitor as described in section 2.3.

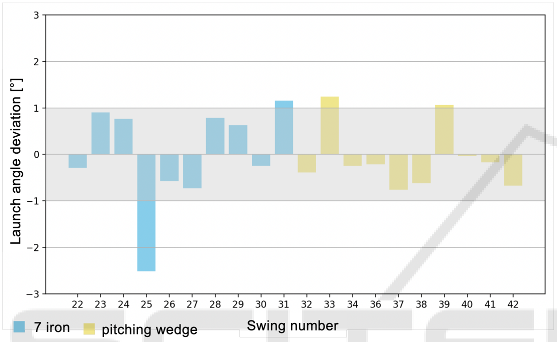

Figure 8: Deviation between the launch monitor results and our approach using a framerate of 60 fps.

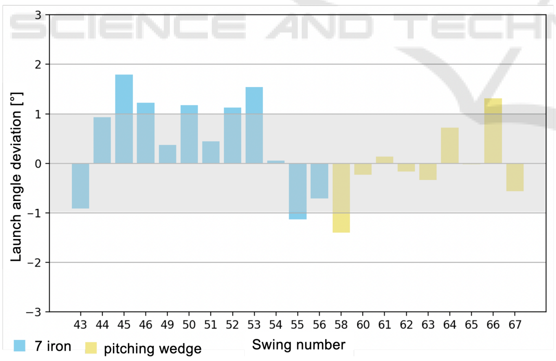

Figure 9: Deviation between the launch monitor results and our approach using a framerate of 120 fps.

The results of the comparison for each swing examined at either 60 fps or 120 fps are shown in Figure 8 and 9 as the deviation between our approach and the used launch monitor in degrees. The tolerance of the Garmin Approach R10 regarding the vertical launch angle measurement is given as $\pm$ 1°. The tolerance range is represented as a gray area in Figure 8 and 9. The computation time for each swing is observed to be ~4 seconds on average with a standard deviation of 1.3 seconds, using a 1,4 GHz Quad-Core Intel Core i5 and an unoptimized code.

It can be seen that our approach provides results that are in strong agreement with the measurements of the Garmin Approach R10. Table 3 shows the absolute average deviation for each used club at each frame rate, along with the combined absolute average deviation. In addition, it can be observed that the overall absolute average deviation is smaller than the tolerance range of the used ground truth system.

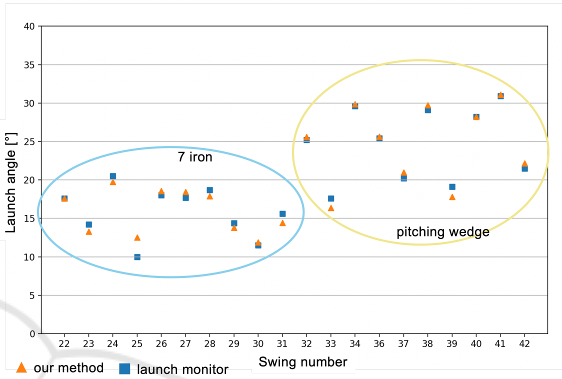

Figure 10: Absolute value comparison at 60 fps.

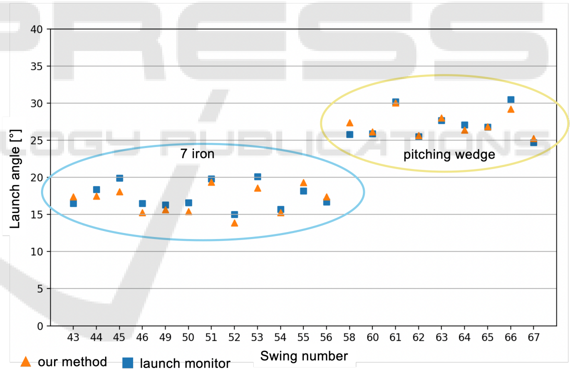

Figure 11: Absolute value comparison at 120 fps.

As we can see in Table 3, the deviation for the club with the higher loft angle, the pitching wedge, is significant lower than the 7 iron. Due to the length difference (see Table 2) between the clubs used, the club head speed of the 7 iron is assumed to be higher than the pitching wedge, which leads to the assumption that the results are speed dependent. Furthermore, isolated deviations can be observed, such as swing No.25 (see Figure 8), which are assumed to be related to the horizontal launch angle as described in the following section. However, looking at the absolute difference in Figure 10 and 11, we can see a high correlation between the results of the different measurement methods.

Table 3: Absolute average deviation of our approach.

Club	60 fps	120 fps	Combined
PW	0.63°	0.59°	0.61°
7 iron	0.77°	0.95°	0.86°
Combined	0.7°	0.77°	0.74°

4 LIMITS

The use of a monocular camera system results in limitations regarding the accuracy of the measurement. Due to the projection on a two-dimensional plane, we have a loss of information about the horizontal launch direction. If the horizontal launch angle is significantly higher or lower than 0°, meaning that the launch direction is to the left or right of the target direction, it will lead to a incorrect measurement. Figure 12 shows that if the launch direction is pointing away from the camera plane, it will lead to a projection on a two-dimensional plane that indicates a higher vertical launch angle than it actually is. Consequently, it will be measured lower if the launch direction is pointing towards the camera plane.

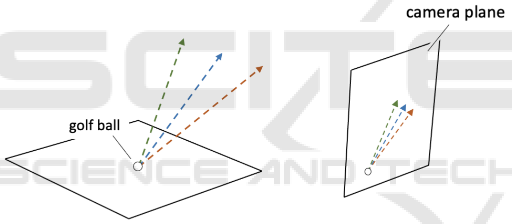

Figure 12: Perspective projection of different horizontal launch angles with constant vertical launch angle.

Therefore, our approach only provides accurate results when the horizontal launch angle is close to zero, meaning the launch direction is similar to the target direction or parallel to the camera plane.

5 CONCLUSION

We presented an approach to measure the vertical launch angle of a golf ball using only video and audio data in combination with a low frame rate, reaching an accuracy equal to the results of a commercial launch monitor, the Garmin Approach R10, using a radar-based method. This means that with our approach, a golf player has the ability to measure the vertical launch angle of their golf shot without the need for specific hardware such as a launch monitor, just a camera and a PC, or any device that combines the two such as a smartphone or tablet.

It should be noted that this approach is designed for offline use only, meaning that we only analyzed pre-recorded video data. However, looking at the results in terms of computation time, our approach has the potential to be an online application leading to a system which is capable of providing direct feedback to the golf player after the golf swing. Therefore, only the audio event detection of the swing detection algorithm needs to be adapted to detect the club impact with the ball without the information after the swing, for example by training a CNN-based audio classifier.

In addition to an online capability, the motion blur detection will also be tested regarding club related parameters such as dynamic loft, angle of attack or club head speed. Concluding a detailed data fusion of audio and video data has a great potential to achieve a higher accuracy of our approach and to develop new methods for launch parameter measurements or golf assistance systems.

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