An automatic, markerless approach to measuring head kinematics in soccer

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I. INTRODUCTION

Numerous studies have aimed to quantify and categorise the kinematics associated with sporting head impact to obtain a better understanding of the mechanisms of brain injury and observed increased risk of neurodegenerative disease resulting from contact sport participation [1-3]. To improve sensitivity of existing methods of head acceleration measurement in sport, such as mouthguards instrumented with inertial measurement units (IMUs), head impact exposure studies often utilise visual confirmation of head impact through video analysis: a heavily time-consuming and resource-intensive process [4]. In an attempt to overcome this issue, previous works have utilised deep learning computer vision algorithms to automatically detect the occurrence of head impact [5]. The present work introduces a fully automated, markerless approach for measuring angular head kinematics using computer vision techniques in an attempt to move towards a more efficient, non-invasive method for extraction of head kinematics.

II. METHODS

The three angular degrees of freedom (DoFs) of the human head are defined as the rotation angles yaw, pitch and roll, as illustrated in Fig. 1(a). Angular head kinematics for these DoFs are here measured through a technique of participant head pose estimation in consecutive video frames by solving the Perspective-n-Point (PnP) problem for a set of facial landmarks on the human head, as illustrated in Fig. 1(b). Solving the PnP problem involves projecting a set of known points from the world coordinate system, $\mathbf{p}_i$, onto the image plane $\mathbf{u}$, using a matrix of intrinsic camera parameters (including values for focal length and principal point), $\mathbf{K}$, to obtain an estimate of the 3D rotation matrix, $\mathbf{R}$, and translation vector, $\mathbf{t}$, of the object for which points $\mathbf{p}_i$ are located on the surface. This can be expressed with the equation: $\mathbf{u} = \mathbf{K}[\mathbf{R}|\mathbf{t}]\mathbf{p}_i$, for which there are several methods for obtaining $\mathbf{R}$ and $\mathbf{t}$ [6].

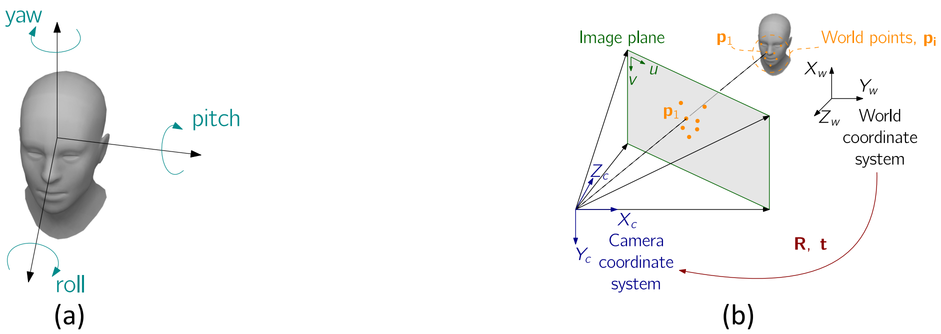

Fig. 1. (a) Definition of head yaw, pitch and roll rotation angles and (b) illustration of the PnP problem for estimating head pose.

The present work adopts in-house software with which participant facial landmarks are detected in consecutive video frames using the MediaPipe Face Mesh Python API, before the PnP problem for a set of landmarks is solved using an iterative method to obtain the head rotation vector. A 110 Hz low-pass 4th-order Butterworth filter is used to reduce measurement noise, before angular velocities for each DoF – ω_{yaw}, ω_{pitch} and ω_{roll}– are calculated from the time-series of estimated head rotations using a simple finite-difference formulation. To provide an initial assessment on the accuracy of this method, a mouthguard-mounted Axivity WAX-9 inertial measurement unit (IMU) is also used to measure kinematics. Two separate videos were recorded for analysis: one in which a deliberate set of movements is performed in each angular DoF; and another in which a low-speed soccer heading action is performed. All videos were recorded in 1280 x 720 pixel resolution at 240 frames per second.

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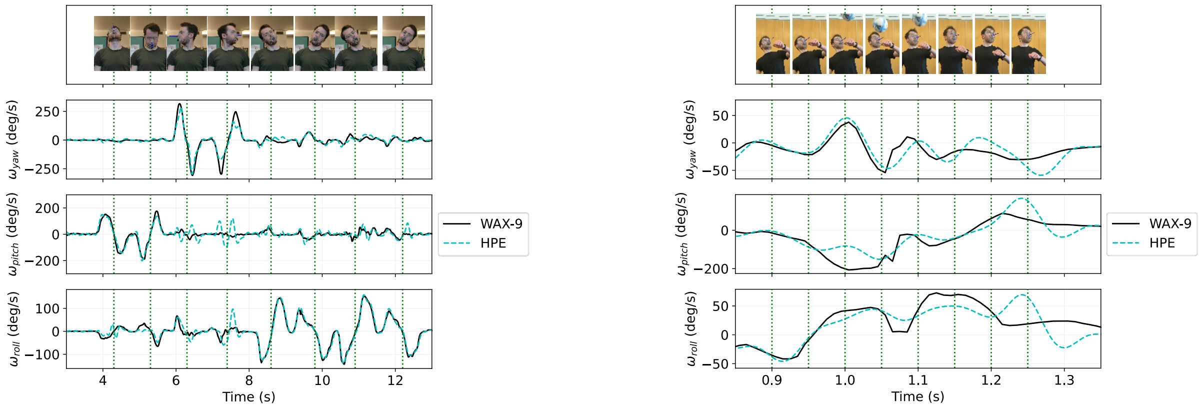
III. INITIAL FINDINGS

Time-series for ω_{yaw}, ω_{pitch} and ω_{roll} obtained using the Axivity WAX-9 IMU (WAX-9) and head pose estimation (HPE) methods during each video are presented in Fig. 2. A set of key frames extracted at selected times are also presented, illustrating range of motion and its relationship with angular velocity. Predictions of maximum angular velocities in each case are summarised in Table I.



(a) (b)

Fig. 2. Time series of angular velocities ω_{yaw}, ω_{pitch} and ω_{roll} in degrees per second (deg/s) obtained using WAX-9 and HPE methods, including key-frames for (a) Case A: a set of deliberate movements by participant and (b) Case B: a soccer heading action.

TABLE I
MAXIMUM PREDICTED ANGULAR VELOCITIES

Case	Quantity	WAX-9 (deg/s)	HPE (deg/s)	Difference (deg/s)	% difference
A	$\lvert\omega_{yaw}\rvert_{max}$	317.3	297.3	20.0	6.3
	$\lvert\omega_{pitch}\rvert_{max}$	189.1	200.9	-11.8	-6.2
	$\lvert\omega_{roll}\rvert_{max}$	152.5	158.9	-6.4	-4.2
B	$\lvert\omega_{yaw}\rvert_{max}$	54.3	46.7	7.6	14.0
	$\lvert\omega_{pitch}\rvert_{max}$	207.0	167.3	39.7	19.2
	$\lvert\omega_{roll}\rvert_{max}$	72.5	69.5	3.0	4.1

IV. DISCUSSION

The obtained maximum absolute values for angular head kinematics using HPE agree closely with those obtained from a more traditional IMU approach (maximum 6.3% difference in Case A and maximum 19.2% difference in Case B). However, in Fig. 2 the presence of additional noise measured in the HPE signal is observed, which future studies should examine in more detail. Increasing the parameters of video resolution and frame rate in future studies will allow for precision to be studied for higher energy impacts with shorter impact durations. It is expected that this will also facilitate the study of the influence of the skin-skull coupling on precision. A further limitation of the proposed HPE method is that it requires facial landmarks to be visible during impact, meaning kinematic data cannot be measured for cases where the entire head becomes obscured. Future studies should examine the degree to which this affects measurement accuracy, as well as examining the influence of multiple-view camera setups, which should ensure greater visibility of the head during impact and extending measurement of kinematics to include linear accelerations in the x, y and z directions, capturing all 6 DoFs.

V. REFERENCES

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