

RECENT PRACTICAL APPLICATIONS OF CLOSE-RANGE PHOTOGRAMMETRY FOR COMPLEX MOTION STUDY

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ABSTRACT:

This paper discusses two practical applications of close-range photogrammetry completed at the University of Otago recently. The applications involve: 1) human spine study; and 2) rugby player's limb coordination. The discussion covers: 1) imaging system design; 2) system calibration; 3) image processing and 3D data capture; and 4) usage of the captured 3D data. Also, the spatial accuracy requirement of these applications and the potential of the close-range photogrammetric technique for these areas of research are highlighted in the paper. Results of the projects show that digital photogrammetry is efficient and accurate for the applications discussed.

1. INTRODUCTION

This paper introduces two recent applications of close-range photogrammetry for the study of the human body in relation to spinal movement and rugby sport players' limb coordination. The main measurements are distances, vectors and angles. The measurements were needed to evaluate the parameters required for their respective studies. Identifiable points or anatomical landmarks within the region of the spine or the limbs are required to obtain accurate measurements. Still-frame/video imaging and laser technology are the best known methods for these types of study. Recent works on human body measurement using video can be found in Figueroa et al. (2003). By and large, hardware and software are readily available off-the-shelf for human motion analysis (Richards 1999). The author reported RMSs of seven major systems were less than 2.0 mm in the RMS.

2. METHODOLOGY

2.1 Spinal study

In the human spinal study, the spinal movement and spinal deformation of athletes were needed to evaluate the occurrence of spinal injury in a gruelling training environment such as military exercises in rough terrain. Generally, in the laboratory, the high performance imaging system such as the Motion Analysis (Motion Analysis Corporation, Santa Rosa, CA) system provides accurate 3D data for motion study. However, the portability and workability of such a system is limited in a harsh outdoor environment. A portable image-capture device was developed to enable in-situ data capture for the study. The device consists of a sturdy aluminium frame which can support four cameras, a rigid control frame, light-fitting and two mounting-brackets for a surveying tripod. The four cameras could take either convergent photography or stereophotography of the whole spinal region simultaneously. The device could be mounted on two surveying tripods for photography in the field. Four Sony Cyber-shot digital cameras and a four-camera

LANC Shepherd (*Graphic Media Research, Canon Falls, Mn US*) remote camera control device were used to synchronise the shutters of the cameras. The cameras were pre-calibrated before images of the patients' spines were captured for the project. To calibrate the cameras, images were taken with a set of temporary retro-targets (Figure 1) fastened onto the control frame and an exterior orientation device as shown in Figure 1.



Figure 1. A convergent image used in the system calibration. Note the temporary retro targets (inside the control frame) used for lens distortion calibration.

In the system calibration, the spine anthropometric landmarks (cervical, thoracic, lumbar, and pelvic) positions were marked by an experienced physiotherapist (Figure 2). Multi-convergent and stereophotography were obtained of the participants' backs at predetermined time intervals throughout the day. Additionally, the framing mode of capturing images was used where the movement must be tracked continuously for a short period. Australis, photogrammetric bundle software (*Photometrix Pty Ltd, Melbourne Australia*) was used to calibrate the camera on-the-job as the handling of the camera could have altered lab calibration. VirtualDub (WWW.VirtualDub.org) image processing software was used for the image process and Australis was used to carry out all the bundle adjustment of the images. The results of the camera

calibration and the system test accuracy are provided in the results and analyses.

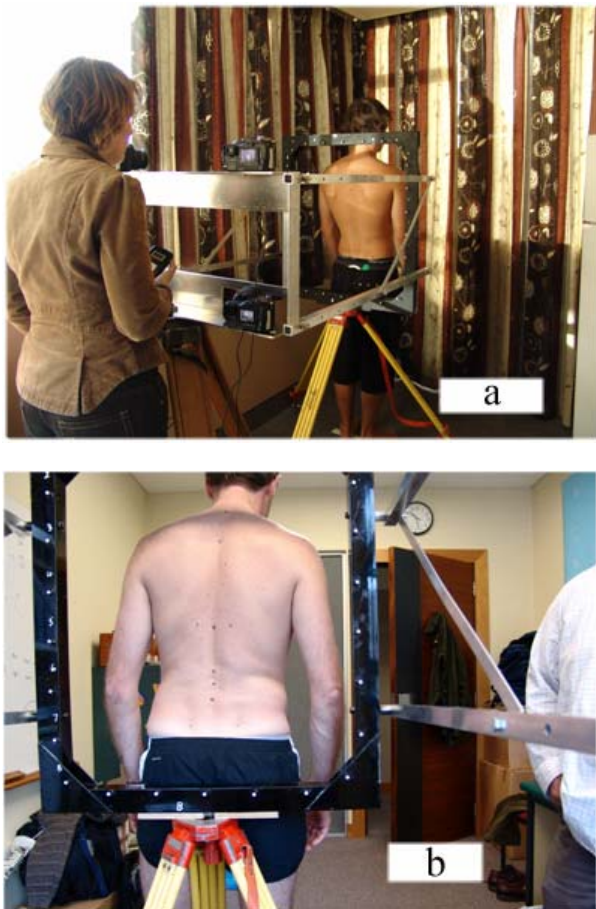


Figure 2. (a) An image of the spine of a project participant and the imaging system. Note the round ink markers of the spine anthropometric landmarks in (b).

2.2 Limb coordination in a rugby game lineout study

The research involves four stages, namely: 1) capture stereovideo clips of a rugby lineout for virtual lineout display on the white screen; 2) create 3D colour anaglyph video clips; 3) acquire players' body segment movement; and 4) compute parameters to determine the quality of limb coordination. Two groups of ball throwers were recruited for the study. The accurate throwers were elite and seasoned players while the inaccurate throwers were occasional players.

2.2.1 Capturing stereovideo clip of a rugby lineout for a virtual lineout scene

A NuView, SX-2000, Stereo3D camcorder adapter (Figure 3a) developed by I-O Display Systems, Sacramento, California was selected for the application. The device allows recording of field-sequential video images of a rugby lineout throw (Figure 3b) onto a DV tape or onto a computer hard drive. The device uses a field-sequential technique to capture stereo-images using a single-lens DV. Accordingly, the device uses mirrors to direct the incoming light rays onto the left and right viewing windows. A set of alternating shutters allows the right and left perspective view to be imaged onto the sensor as odd and even fields. Hence, each frame of video footage consists of a view from the left window as odd fields and a view from the

right window as even fields. Consequently, each frame can be field-decoded (deinterlaced) to form left and right stereo-images.

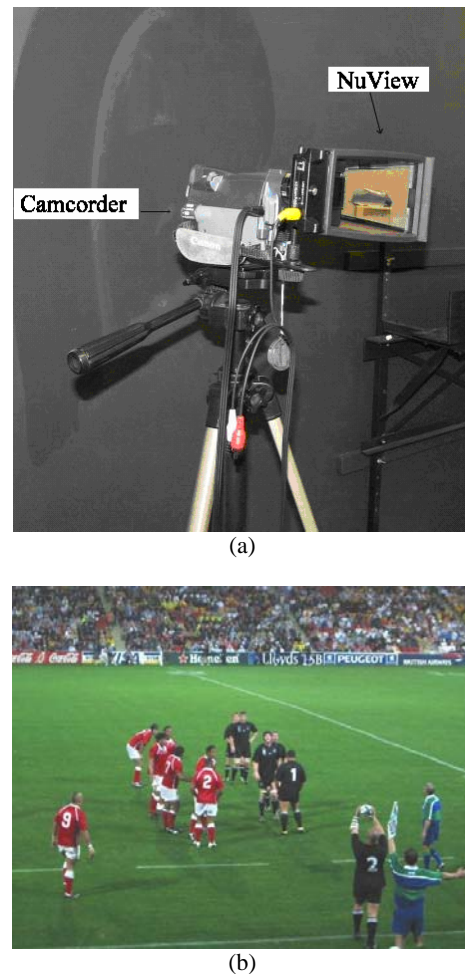


Figure 3. a) NuView 3D imaging device; b) Scene of a rugby lineout throw.

To capture the 3D video footage for the virtual lineout scene, two standard 50 Hz DV cameras were placed perpendicular to, and directly in front of each real lineout in order to estimate where the optimal point in space was for the ball to be caught. Also, a Sony HDV 50 Hz camera, with NuView, SX-2000, Stereo3D camcorder adapter, was located directly in front of the lineout at a height similar to that of a thrower's head (Figure 4). The NuView 3D camera was approximately 5m behind the sideline, 5m behind where the thrower would stand, for optimal depth perception. This was determined through testing of the NuView hardware as demonstrated by Chong and Croft (2005).

In the lineout simulation, thirty lineouts were performed to the distances close to six (front jumper), 10 (middle jumper), and 14 (back jumper) metres as these were the distances estimated to be where the two, four, and six jumpers would be in a real lineout (Figure 4). The player formation was as follows: lifter, jumper, lifter, jumper, lifter, jumper, and lifter, with the jumpers entering the lineout at the nominated positions and the lifters standing at even distances between these. The jumper and lifters then performed each jump in their own time yet no balls were actually thrown, rather the players were asked to imagine one being thrown.

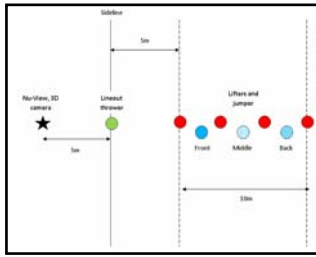


Figure 4. Relative position of the ball-thrower, jumper and stereovideo capture system during the stereo-video capture exercise.

2.2.2 Creating 3D colour anaglyph video clips

Once the lineout simulation video footage was captured, it was downloaded into individual lineout files at a resolution of 1320 x 1080 pixels. Each of these files was then de-interlaced using a free software package called VirtualDub 1.7.5. (Lee 2005). This produced two video files which had slightly different angular offsets, as if they were from the perspective view of the left and right human eyes. The two video files were then colour tinted cyan (blue and green) and red using 3D Combine 4.2.5 (Scullion, 2008). Finally the two-colour tinted video files were overlaid and saved as one high resolution MPEG file with 3D Combine. This was repeated for all lineout trials.

2.2.3 Acquisition of Rugby Players' Body Segment Movement

2.2.3.1 Ball-throw accuracy checking device

A device (throw accuracy measurement or TAM) was designed and built for this study to enable a reliable measurement of throw accuracy. It consisted of 28 lasers arranged in two grid shaped planes beaming onto 28 light dependent resistors, which were being analysed by a small processor for any incidence of a laser being broken (Figure 5). The time and position information was then sent to an analysis computer running a Matlab (*MathWorks Inc, Natick, Massachusetts, USA*) routine which calculated the parabolic flight path of the ball.

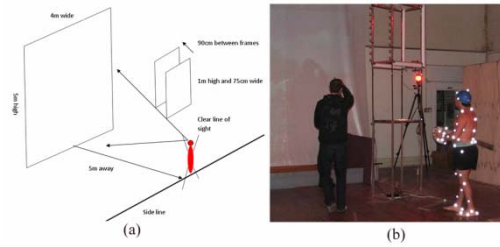


Figure 5. Custom-built throw accuracy measurement (TAM) device; (a) a schematic diagram showing the projection screen, the device and the thrower's position; (b) a ball-thrower prepares for a throw. Note the retro-targets on the thrower's body.

The computer program calculated the position where the ball's flight path would have intersected the coronal plane of the jumper's hands, and showed this point as 2D coordinates (Figure 6). Tests show that the theoretical parabolic error from the positioning of the lasers was 30 cm for a throw 15 m long. It should be noted that the position of the ball's intersection on the coronal plane was predicted even if the ball did not reach the plane before hitting the ground.

2.2.3.2 Body segment movement tracking

A qualitative pilot study (Croft 2007) identified important parameters in determining throw accuracy: hip and torso orientation; elbow separation; front foot step; rear foot push; trunk flexion; body weight transfer; and hand-follow-through. Therefore, parameters describing these aspects were investigated in this study. In the study, all of the movement variables were observed to be present in either one or two of the throw phases, hence for the purpose of this study they will only be analysed in these relevant phases as in Table I. Only Phase I is discussed in detail in this paper.

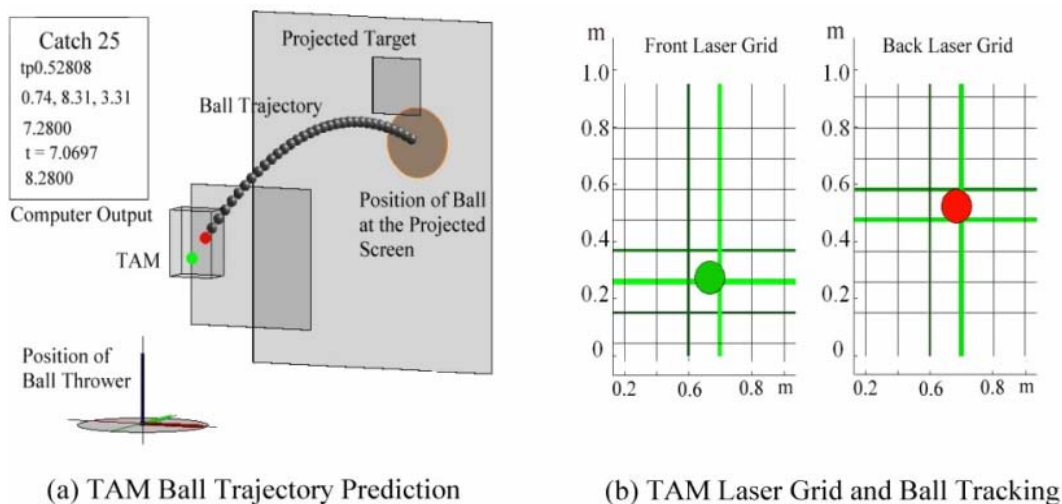


Figure 6. Prediction of the flight-path of the rugby ball as determined by the TAM device.

Phase I: Preparation	Phase II: Delivery	Phase III: Follow through
Hip and torso orientation	Hip and torso orientation	
Elbow separation	Elbow separation	
		Hand follow-through
Front foot step	Front foot step	
		Centre of mass transfer
	Rear foot push	Rear foot push
Trunk flexion	Trunk flexion	

Table 1. Throw phase and type of measurement required

Phase I: Preparation

The preparation phase starts when the player’s hands first start moving backwards in the act of throwing the ball, and ends when the ball is at its furthestmost point behind the player’s head, about to change direction towards target (Figure 7a; b). This phase consists of: i) hip and torso orientation; ii) elbow separation; iii) front foot step; and iv) trunk flexion. These movements are described and illustrated below.

i). Hip and torso orientation

The hips and the shoulders should be perpendicular to the target or very close to perpendicular at setup and during delivery of the throw (Figure 8a). The variable measured is the hip and shoulder angle.

ii). Elbow separation

The elbows must stay a constant distance apart in relation to the shoulders during the throwing action. The variable measured is the elbow width (Figure 8b).

iii). Front foot step

The player must make a step towards the target and this will increase with the length of the throw. The variables measured are the step length and its direction (Figure 8a; b).

iv). Trunk flexion

The player will flex his trunk during throwing, especially on longer throws. The variable measured is the absolute trunk angle.

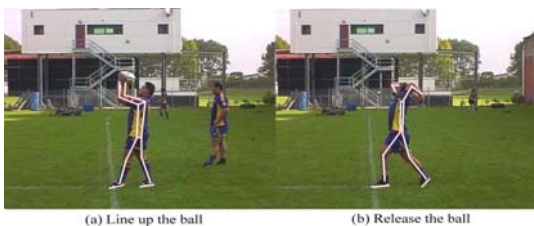


Figure 7. Phase I: Preparation for ball throwing.



Figure 8. (a). Hip and torso orientation; (b). Elbow separation.

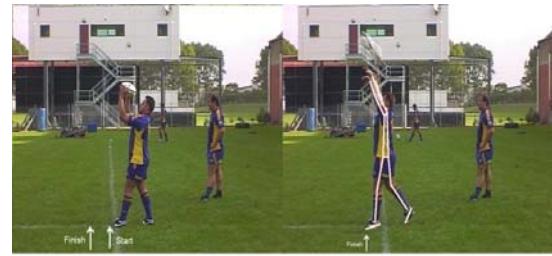


Figure 9. Front foot step position before and after throw.

3. RESULTS AND ANALYSES

3.1 Spine study

The system calibration shows that the 3D measurement accuracy is 0.8 ± 0.35 mm. Table 3 shows the vector change between the morning and the dinner epoch. The positions of the anthropometric landmarks used in the study are shown in Figure 10. Table 4 shows the angle change in the saggital plane between the morning and dinner epoch.

Part of spine	Change (mm) Am-Pm	SD	Comments
Vector T1-PSIS	10.2	5.6	0.6% of height of subject
Vector T1-L1	6.7	3.4	66% of vector T1-PSIS
Vector L1-PSIS	3.7	5.3	36% of vector T-PSIS

Table 3. Vector change between the morning and the dinner epoch measurements.

Part of spine		Change (degrees) Am-Pm	SD	Comments
Thoracic angle		1.7	2.2	
Lumbar angle		-0.4	4.0	
Thoracolumbar angle	Back	-1.9	2.7	0.8% of population
Thoracolumbar angle	Front	-0.6	6.0	88% of population

Table 4. Angle change in the saggital plane between the morning and the dinner epoch

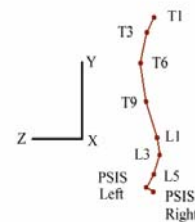


Figure 10. A graphic plot of the spine anthropometric marks.

3.2 Limb coordination study

3.2.1 TAM measurement

As discussed elsewhere the accuracy of a throw was measured by the TAM system. Figure 4 shows the three positions where the designated jumper could appear along the middle of the two-row of jumpers during a throw, namely: 1) at the front; 2) at the middle; and 3) at the back. Throwers were informed of the position of the virtual jumper before each throw at the

projected images. According to Donner and Cunningham (1984) trials with limited participants in a study the throw accuracy values can be mixed for statistical analysis. Therefore the values were separated into two groups: 1) accurate throw for the top 40%; and, 2) inaccurate throw for the bottom 40%. The remaining 20% of the middle values were discarded. The results based on the grouping are presented in Table 1.

Throw Condition	Distance from target (m)	
	Accurate group (n=25)	Inaccurate group (n=25)
	Mean	Mean
At the front	0.530	1.091
At the middle	0.744	2.784
At the back	1.611	8.441

Table 5. Accuracy scores for all throws collected, across all throw conditions.

3.2.2 Lineout thrower's motion

Details of the results and analyses of all movements measured can be found in Croft (2007). However, some significant findings are provided below.

i) Front foot step distance

Figure 11 shows the scatter plot of data spread for the front foot step distance over a short throw (jumper at the front position) condition for the accurate and inaccurate groups. It is apparent that there were more outliers coming from the inaccurate group. Also it is evident that on the average accurate throwers have longer front foot step distances for the long distance throw (Figure 12). A Kolmogorov-Smirnov test for normality and a square root function to normalise the front foot step distance residuals were carried out. The displacement that the thrower's front foot travelled during the first two phases of the throw was then compared with a two-way ANOVA for accurate and inaccurate groups over the three distance conditions (Figure 12).

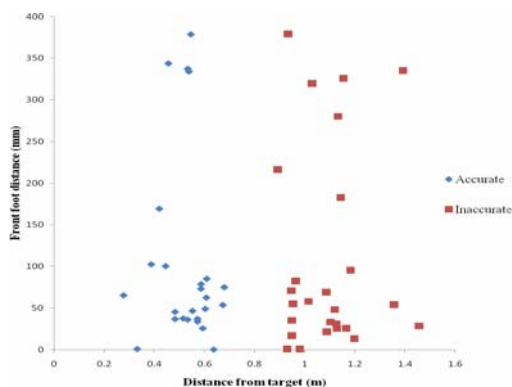


Figure 11. Scatter plot of data spread for front foot step distance over a short throw (at the front position) condition for accurate and inaccurate groups.

The accurate group had a significantly ($F_1=21.5, P<0.000$) higher score (177 ± 14 mm) than the inaccurate group (82.5 ± 13.7 mm) across all three throw distances. Bonferroni t -tests ($P<0.0167$) were run showing significant differences at the middle ($T=4.17, P<0.000$) and long ($T=4.06, P<0.000$) throw conditions between the accuracy groups.

The clinical significance test found a 100% probability of a clinically positive result (Hopkins 2001). The interaction between the accuracy and distance independent variables was also significant ($F=5.18, P<0.007$). This interaction can be observed in Figure 12. The figure clearly shows that accuracy is also affected by an increase in distance and distance of throw (the column length between accurate and inaccurate group in the 'back').

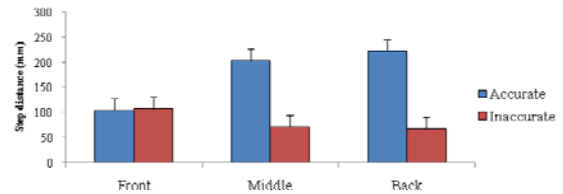


Figure 12. Mean and standard error of the front foot step distance for all throw distance conditions.

ii) Trunk flexion

Figure 13 shows a scatter plot of the data spread for trunk flexion over short throw conditions for the accurate and the inaccurate groups. The throw accuracy for the first group (between 0.25 and 0.64 m) is significantly higher than the second group (0.85 and 1.5 m). However, the majority of the groups show a trunk flexion of 4.5 to 7.5 degrees. Figure 14 shows the mean scores and the standard error the mean scores of the angle of trunk flexion for all throw distance conditions. For the front throw the size of the angle of trunk flexion between the groups was insignificant but the value differs by more than one degree for the middle and the back throw conditions. The absolute mean angle was compared using a two-way ANOVA for accurate and inaccurate groups over the three distance conditions. There was a statistically significant difference ($F_1=6.69, P<0.011$) between accurate ($5.9 \pm 0.2^\circ$) and inaccurate groups ($6.7 \pm 0.2^\circ$) across all three throw distances (Figures 13 and 14). A clinical or practical significance test presented mixed results with a 51% probability of a clinically trivial result, with 40% for clinically positive and 9% for clinically negative results.

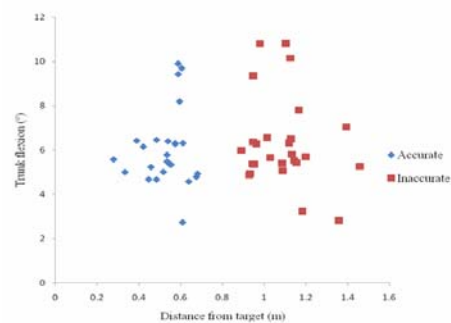


Figure 13. Scatter plot of data spread for trunk flexion over short throw condition for accurate and inaccurate groups.

Although there was a significant result for the accuracy condition the Bonferroni t -tests ($P<0.0167$) indicated no significant differences between the accuracy groups at different throw conditions (Figure 14). This was possibly because the P -value for significance was reduced from $P<0.05$ to $P<0.0167$ to avoid Type I errors.

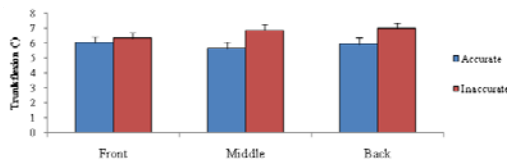


Figure 14. The mean and standard error of the trunk flexion angle for all throw distance conditions.

4. CONCLUSION

The accuracy of the 3D measurement of both applications shows that the collected information satisfied the projects' accuracy requirements. The developed techniques are not only low-cost but will also provide a very reliable and portable system for the study of sport-performance and sport injury prevention.

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