

# VALIDATION OF A SINGLE CAMERA 3D MOTION TRACKING SYSTEM

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## INTRODUCTION

Three-dimensional kinematics of the lower limb during dynamic activities have been shown to be predictive of ACL injury [1]. Motion tracking outside of a laboratory environment is a critical next step in applying ACL research findings to the general population. The Retro-Grate Reflector (RGR) is a new technology that allows for 3-D motion capture using a single camera [2]. An RGR target is constructed by applying artwork on the front and back of a transparent substrate, such as a glass or plastic plate (Figure 1).

**Figure 1:** RGR target. Moiré patterns change as orientation of target changes.

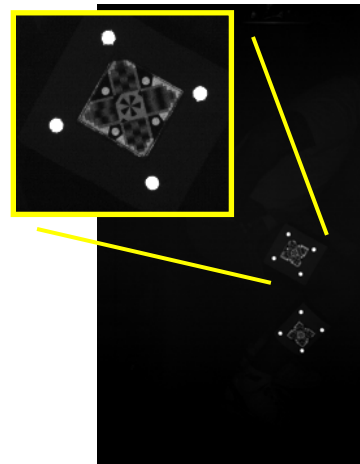


The three-layer structure of substrate and artwork produces moiré patterns, which are seen as light and dark fringes. The moiré patterns respond to changes in orientation. Small rotations produce moiré-pattern displacements that are visible to the eye. With the out-of-plane rotations revealed by the moiré patterns, the RGR system is able to determine 6-DOF pose from a single camera image. Armstrong et al. [2] reported  $\pm 0.0082$  deg RMS error over a  $54^\circ$  measurement range. O'Connor et al. [3] compared the orientation and position information recorded by the RGR system with data recorded with a traditional multi-camera system. The six degree-of-freedom pose data correlated greater than 0.99 between systems. That study used a series of static poses, and the technology has since been refined to record moving pose information from multiple RGR targets at a sampling rate

adequate for assessment of human movement. Therefore, the purpose of this study was to compare motion data for standard athletic movements recorded simultaneously with the RGR and multi-camera (Motion Analysis Eagle) systems.

## METHODS

Nine subjects performed three single-leg land-and-cut maneuvers from a 35 cm high box. Thigh and shank three-dimensional kinematics were collected with the RGR and Eagle camera systems simultaneously at 100 Hz. Plates with four reflective spheres were attached to the thigh and shank, and an RGR target was mounted to the center of the plate (Figure 2).



**Figure 2:** Camera image at maximum knee flexion. Inset provides greater detail of target and marker mounting.

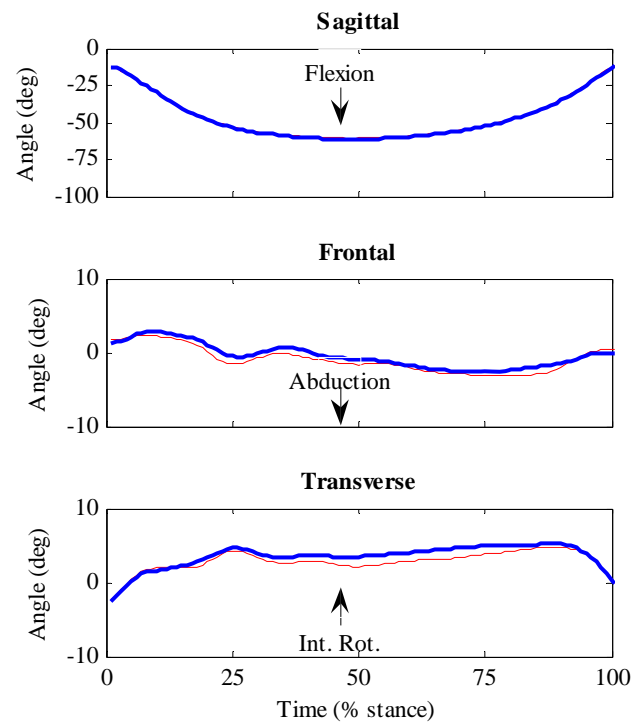
Prior to data collection, the coordinate systems of the two measurement systems were co-registered using a sequence of 30 static poses of a four marker plate with an RGR target rigidly attached. The

RMS errors between RGR-target and Eagle-based pose information were calculated from the static poses. The RMS error for pitch, roll, and yaw were 0.57°, 0.68°, and 0.79°, respectively. The spatial RMS errors were 4.2, 6.0, and 3.9 mm. During the cutting task, thigh and shank pose information was recorded simultaneously by a Motion Analysis 7-camera Eagle system (Santa Rosa, CA) and a Basler A501k (Ahrensburg, Germany) 1.3 MPixel camera. After attaching the plates, a standing trial was recorded and all kinematic information were reported relative to the standing orientation. All raw kinematic data were filtered at 12 Hz. The six-degree-of-freedom pose of the thigh and shank were calculated for the Eagle-based measurements using a standard cross product approach. Segment poses were also calculated based on the information intrinsic to the RGR target. Knee angles in the three planes were calculated using a joint coordinate system approach [4]. Touchdown and peak angles were compared using a dependent t-test ( $p < .05$ ).

## RESULTS AND CONCLUSIONS

The time series of the knee angles in the sagittal, frontal, and transverse planes matched closely (Figure 3). There were no differences in the kinematic variables between the Eagle and RGR measurements in any plane (Table 1). In addition, most dependent variables correlated strongly between the two systems. The only discrepancies appeared in the frontal plane, where there was trend suggesting a difference in peak angles and a moderate correlation in touchdown angles. The way in which the segment local coordinate systems were defined was based on the assumption that subjects were perfectly aligned with the room coordinate system. It is likely that this was a false assumption, which would lead to cross talk between planes. Any small differences in Eagle and RGR measurements may have been magnified by this effect. In summary, these results strongly support

the ability to use the RGR technology as a valid 3-D motion capture system.



**Figure 3:** Joint angles in all three planes. The thick blue line represents the RGR measurements and the thin red line represents the Eagle measurements.

## REFERENCES

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## ACKNOWLEDGEMENTS

The authors would like to thank the UWM Research Growth Initiative and the NIH (1R15AR056117-01) for their financial support of this project.

**Table 1.** Comparison of knee joint kinematics collected with the Eagle and RGR systems.

	Sagittal		Frontal		Transverse	
	TD	Peak	TD	Peak	TD	Peak
<b>Eagle</b>	-13.9 (7.6)	-68.4 (13.6)	1.9 (2.1)	-6.8 (6.8)	-2.6 (4.9)	7.7 (4.7)
<b>RGR</b>	-14.0 (7.6)	-68.9 (13.8)	1.4 (2.8)	-5.6 (7.7)	-2.7 (5.9)	8.6 (5.8)
<b>Difference</b>	0.1	0.5	0.5	-1.2	0.1	-0.9
<b>p-value</b>	0.411	0.096	0.238	0.053	0.440	0.102
<b>r</b>	0.97	0.99	0.57	0.97	0.94	0.95